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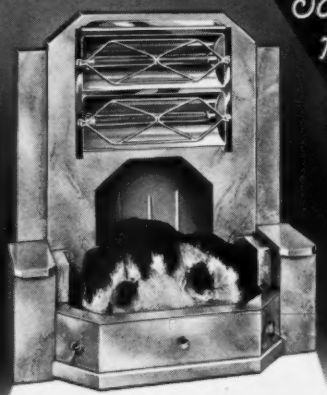

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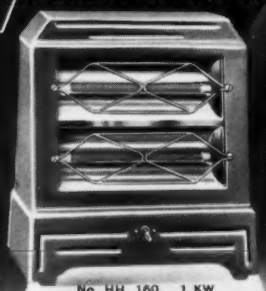

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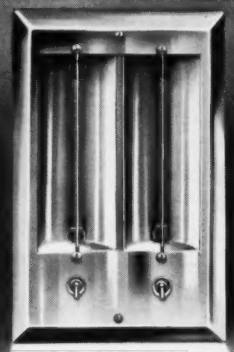

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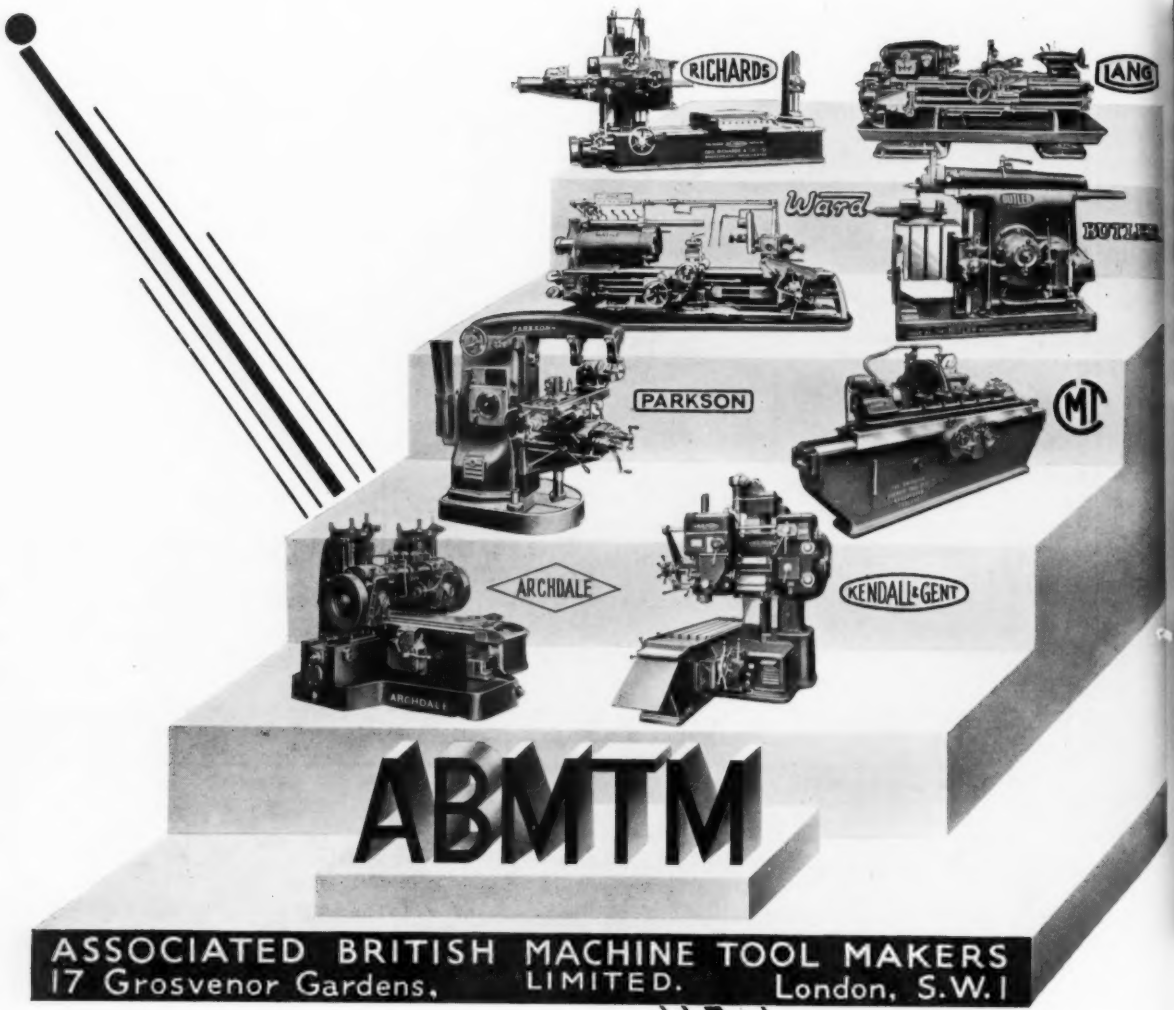

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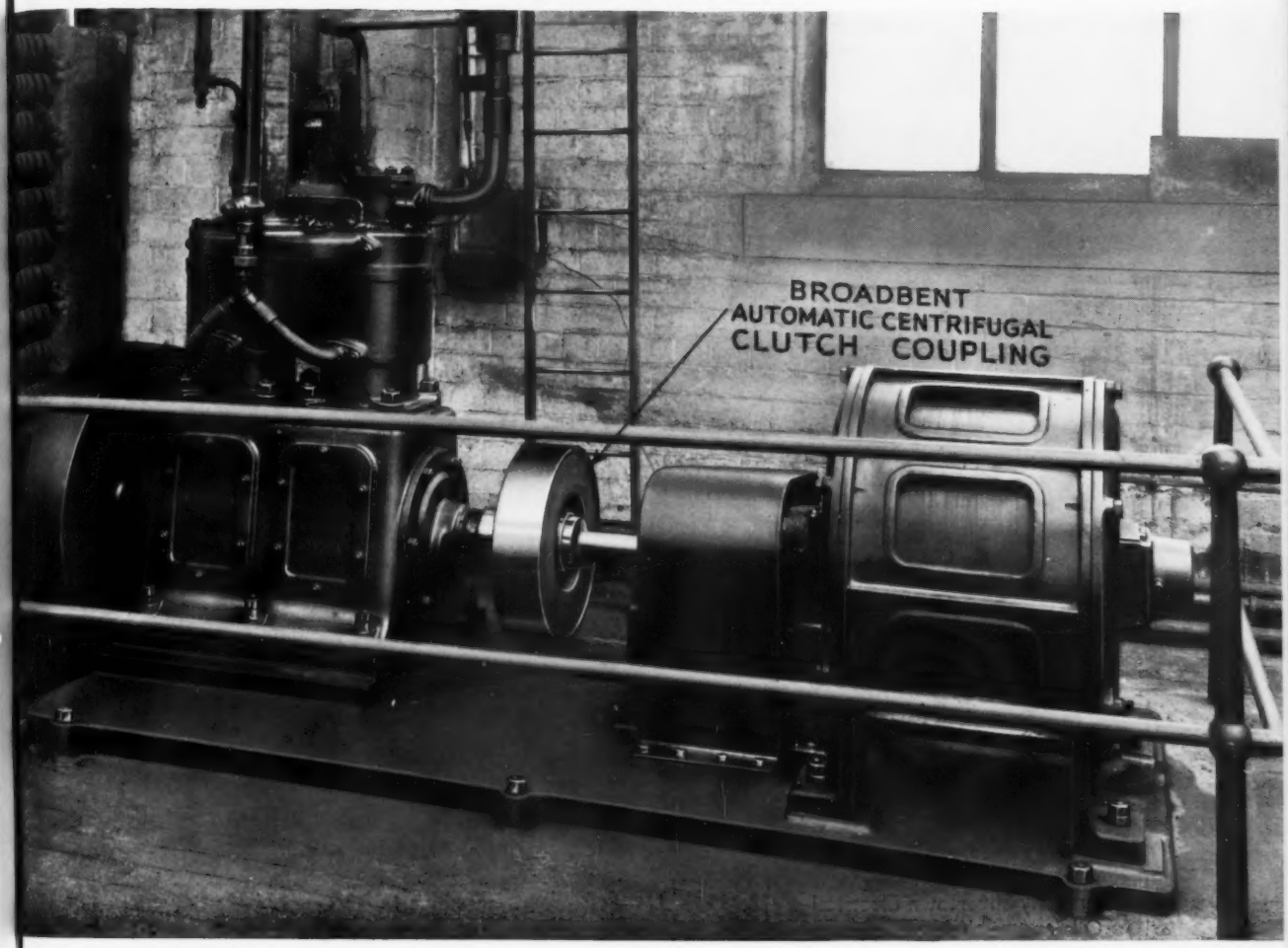

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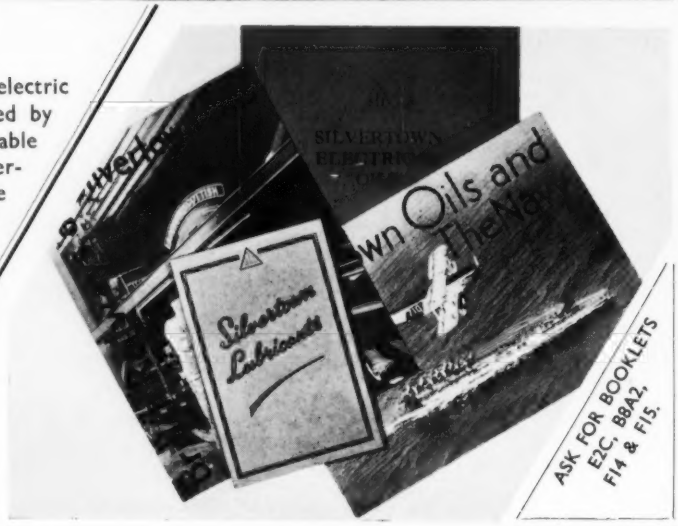

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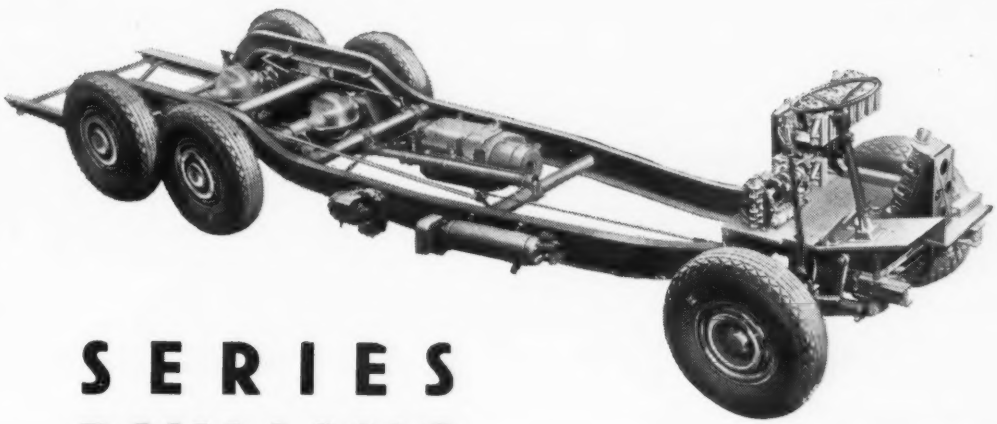

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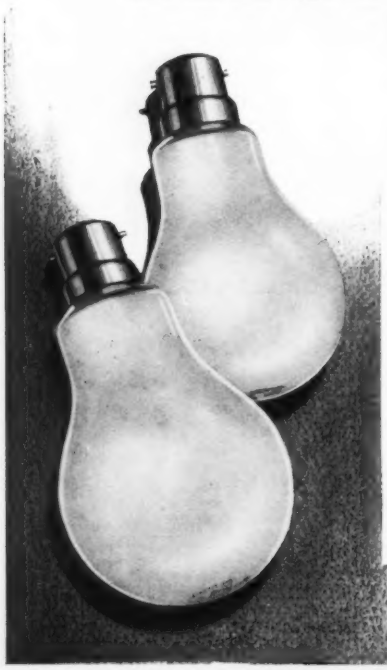

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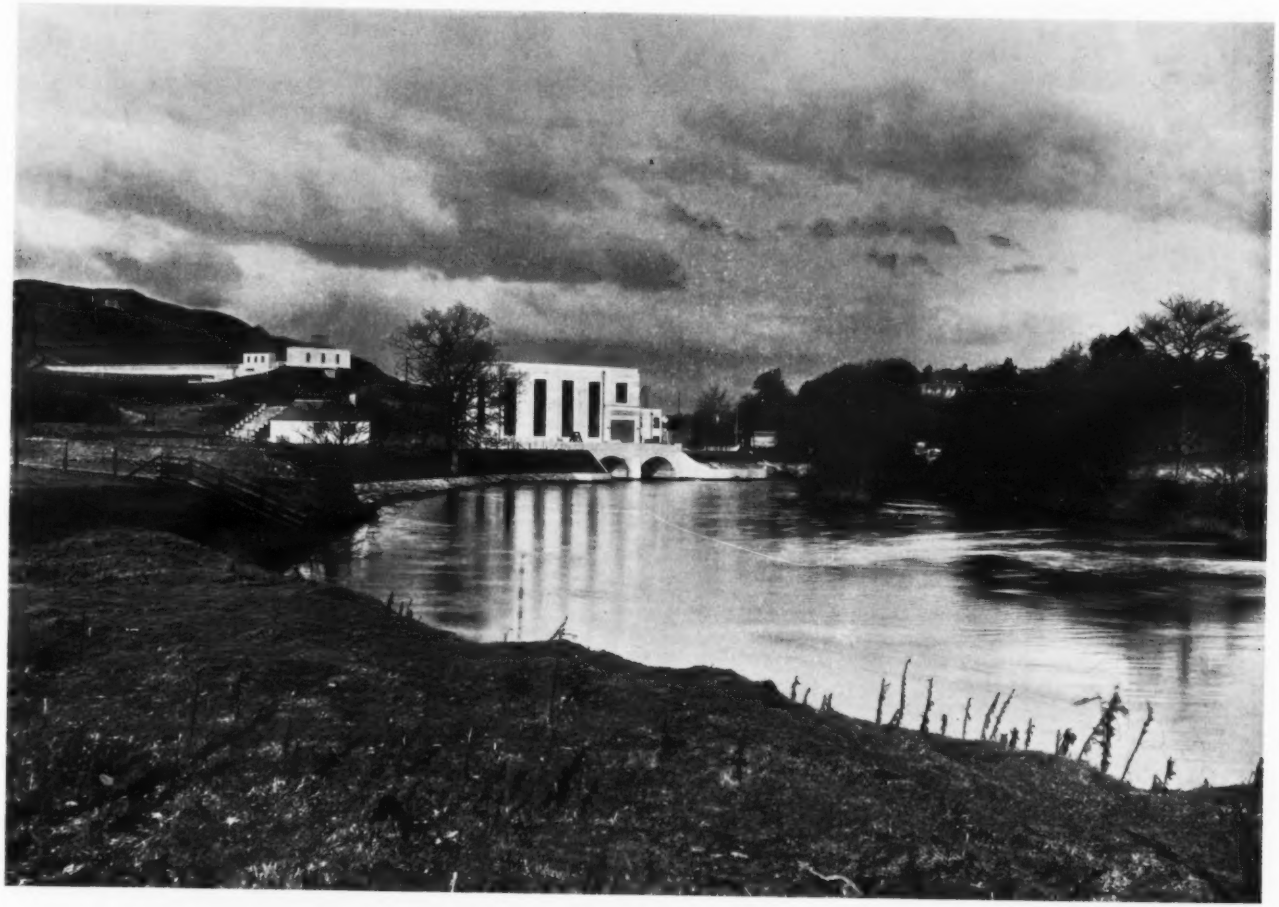

The Earlstoun Power Station of the Galloway Water Power Company.

The English Electric Journal

Vol. VIII. No. 8 DECEMBER, 1937 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

Readers will recall that in Nos. 1, 2 and 3 of this volume of the "English Electric Journal" Mr. H. L. Bazalgette contributed a series of articles on the first stage of the Galloway Water Power Company's Hydro-Electric Scheme. In the first article in this issue Mr. Bazalgette describes the second stage of this exceptionally interesting scheme.

It is sometimes asserted that power developments in Great Britain—however bold and original their design and construction—do not exercise the same popular appeal or receive the same appreciation as certain other types of engineering works. However this may be, it is noteworthy that, visiting Engineers from many countries have expressed their appreciation of the design and execution of the Galloway Hydro-Electric Scheme, which is destined to occupy a high place in British engineering achievement. It is very gratifying that our Company has been able to contribute so largely to the success of this scheme.

We hope to be able to give some interesting operating figures in a future number of this Journal.

With the demand of modern electricity supply undertakings for steam turbines of large outputs and high efficiencies, the designer has been confronted with a number of problems, one of the most important of which is the design of the last row of blades at the exhaust-end of the turbine. In his article "'The English Electric' 'Optimum' Blade for Steam Turbines of Large Outputs," Mr. F. J. Cowlin describes the development of the Company's side-entry 'Optimum' blade designed to meet modern operating conditions.

The last article, entitled Railway Electrification in Poland, is concluded from our previous issue (Vol. VIII., No. 7). The overhead line equipment, multiple-unit stock and locomotives are dealt with. We give below an extract from a paragraph under the heading "We prefer Electricity to Steam," which appeared in the Polish newspaper "Express Poranny," and deals with the increase in passenger traffic which has followed the electrification of the Warsaw Suburban Lines.

"The Polish State Railways, statistics show that the passenger traffic on the electrified suburban lines has considerably grown. Since the electric trains have been put into service the frequency on the Zyrardow line has increased 25% above the average figure, and on the Otwock line 100%.

"The results are above all expectations, the Polish State Railways Management having expected the passenger traffic to rise 15% above the average figure."

Important Trolley Bus Contract for Bradford Corporation.

The English Electric Company have received a contract from the Bradford Corporation for 57 complete Trolley Buses. These will be of the 2-axle type with double-deck all-metal bodies, providing seating accommodation for 56 passengers. The vehicles will be provided with low-tension lighting throughout. Forty-two of the vehicles will be on A.E.C. chassis.

The Trolley Buses will be fitted with an 80 h.p. motor, and control will be by means of the English Electric Company's Series Dynamic System. It is noteworthy that the decision of Bradford Corporation to adopt the Series Dynamic Control System for their vehicles follows extensive trials which they have carried out with this type of control.

British Industries Fair, Birmingham, February 21st to March 4th, 1938.

A cordial invitation is extended to all our readers to visit the Company's Stand No. Cb611 : Cb510 in the Electrical Section of the Fair. Exhibits will include a complete range of Domestic, Heating and Cooking Appliances, including Electric Fires, Cookers, Water Heaters, Washing Machines and Irons. A wide range of industrial Fusegear, examples of Switchgear, Fractional Horse Power Motors and House Service Meters.

The Galloway Water Power Scheme.

Second Stage of the Development.

By H. L. BAZALGETTE, A.C.G.I., A.M.Inst.C.E., A.M.I.E.E.

Second Stage of the Development.

In three articles published in Vol. VIII, Nos. 1, 2 and 3 of this Journal the plant comprised in the first stage of the Galloway Water Power Scheme was described, and in the present article it is proposed to deal with the second stage, which has now been completed.

It will be recalled that the whole Scheme includes the five Power Stations at Tongland, Glenlee, Earlstoun, Carsfad and Kendoon; it is the last three which constitute the second stage of the Scheme, and their locations can be found on the map on page 254 which is being republished in this issue for ease of reference.

Broadly speaking, while the works of the first stage of the development were mainly concerned with the regulation of the River Dee for generation of hydro-electric power at Tongland and Glenlee, those of the second stage consist of the regulation of the Water of Ken in its higher reaches for the production of power at Kendoon, Carsfad and Earlstoun Power Stations.

At the North-West corner of the map will be found Loch Doon where a dam has been erected at the Northern end to raise the level and to create a reservoir, which is fed by the various streams which normally run into it.

By an ingenious arrangement it is also fed by the waters of the Deugh and Bow Burn, which normally flow to the South East. Bow Burn has been dammed so that it flows into the Deugh and a tunnel has been driven from the Deugh to Loch Doon, crossing on its way a stream known as Carsphairn Lane, where a syphon pipe has been constructed. Carsphairn Lane joins the lower stretches of the Water of Deugh and, by means of valve control at the bottom of the syphon, the water impounded higher up can, if desired, be made to flow in that direction. Thus the water from the Deugh and Bow Burn may either be stored in Loch Doon during the wet season when water is abundant, or during dry periods it can be directed down Carsphairn Lane in order to maintain the necessary minimum flow.

Below the village of Carsphairn, dams have been constructed across the Waters of Deugh and Ken in order to form a daily storage reservoir for Kendoon Power Station, which is fed by a closed adqueduct terminating in a surge tower and from that point by steel pipelines.

About one and a half miles below Kendoon a dam has been raised across the Ken to provide storage for Carsfad Power Station, which is supplied by a canal and pipeline. Two miles further down the river another dam has been made to impound water for Earlstoun Power Station, which discharges into the River Ken.

It will be seen from the foregoing that the three Power Stations of the second development are served by the same water and that, in addition to large seasonal storage, small reservoirs are provided for day to day working. The second stage is thus, in its conception and operation, similar to the first stage of the development; the whole scheme is primarily designed for peak load operation, and is also endowed with considerable flexibility so that, when water is abundant, the plant can be run at full capacity for long periods.

The first development, comprising Tongland and Glenlee Power Stations, has an aggregate capacity of 57,000 kW., and the three stations of the second stage aggregate 45,000 kW., making 102,000 kW. for the whole scheme. The respective catchment areas, heads and installed capacities of the five Power Stations will be found on page 7, Vol. VIII, No. 1, of this Journal.

All five stations are connected to the 132 kV. Grid line and Plate I in Vol. VIII, No. 3, of this Journal shows the manner in which the Kendoon, Carsfad, and Earlstoun Power Stations are linked with the rest of the system. A feature of outstanding interest which will be described hereafter, is the automatic starting up and shutting down of the plant at Carsfad and Earlstoun from Glenlee Power Station by means of supervisory gear.

In the execution of the civil engineering works and buildings of the first stage great care was

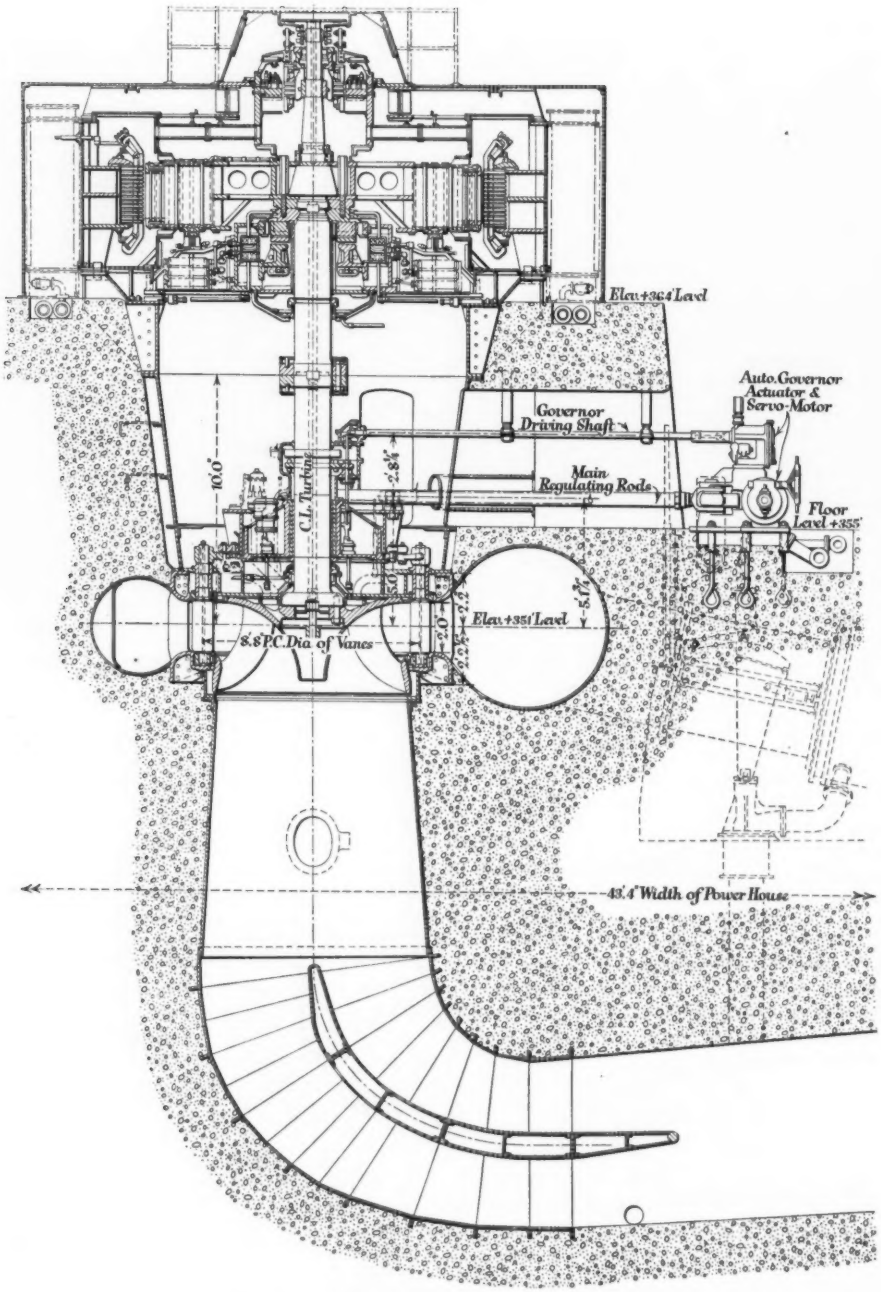


Fig. 33.—Cross Section through Kendoon Water Turbine and Generator.

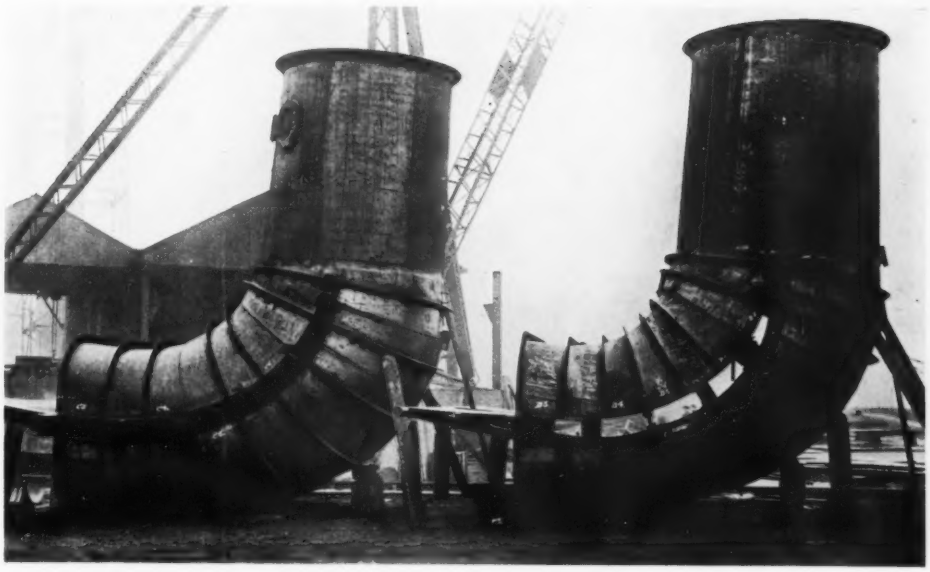


Fig. 34.—Draught Tubes assembled.

exercised to preserve the natural beauty of the scenery, and the same care has been taken in executing the second stage works. The frontispiece illustrates a photograph of Earlstoun Power Station and intake, taken on a November day in 1936, and this photograph serves to prove the fact, which cannot be emphasised too often, that the execution of hydro-electric works does not necessitate those unsightly features which accompany many less useful enterprises.

Plant Contracts.

In the early part of 1934, when the first stage was well under way, the contracts for the plant for the three Stations of the second stage were placed with the English Electric Company. These comprised, in addition to the generating plant, the main and automatic switch and control gear at Carsfad and Earlstoun, and the complete heating and lighting installations and cable connections at these two Power Stations. As in the case of the first stage, the contracts also included delivery to site, erection, and placing into service of the whole equipment.

The general experience gained on the first stage was necessarily of the greatest value in executing the somewhat similar contracts of the second stage. The same favourable arrangement was made with the Railway Company whereby they undertook the overall responsibility for delivery by rail and road, including handling from rail trucks to road vehicles, and deliveries were effected from Works to site without hitch or delay.

Messrs. Merz and McLellan acted as Consulting Engineers for the plant and Sir Alexander Gibb and Partners for the civil engineering works.

Kendoon Power Station.

Kendoon Power Station is equipped with two 16,500 h.p. vertical-shaft reaction water turbines working under a maximum head of 156-ft. and driving at 250 r.p.m. vertical-shaft umbrella-type alternators, each designed to give a normal three-phase output of 10,500 kW., 0.8 power factor, 11,000 volts, 50 cycles, and a maximum output of 11,600 kW.

Fig. 33 shows a cross section through the turbine and alternator, and it will be observed that the design follows the general lines of the unit for Tongland, described in a previous issue. The single-floor layout was again chosen, the main advantage of which is its great accessibility; fabrication by electro-welding was again largely adopted in the construction of the whole unit. The generator rests on a fabricated steel support surrounded by concrete strongly reinforced to provide a pedestal, which forms a solid block with the upstream wall of the station. As in the case of Tongland, all the auxiliary equipment, such as governors, servomotors, oil pumping sets, pressure receivers, etc., stand on the floor at the

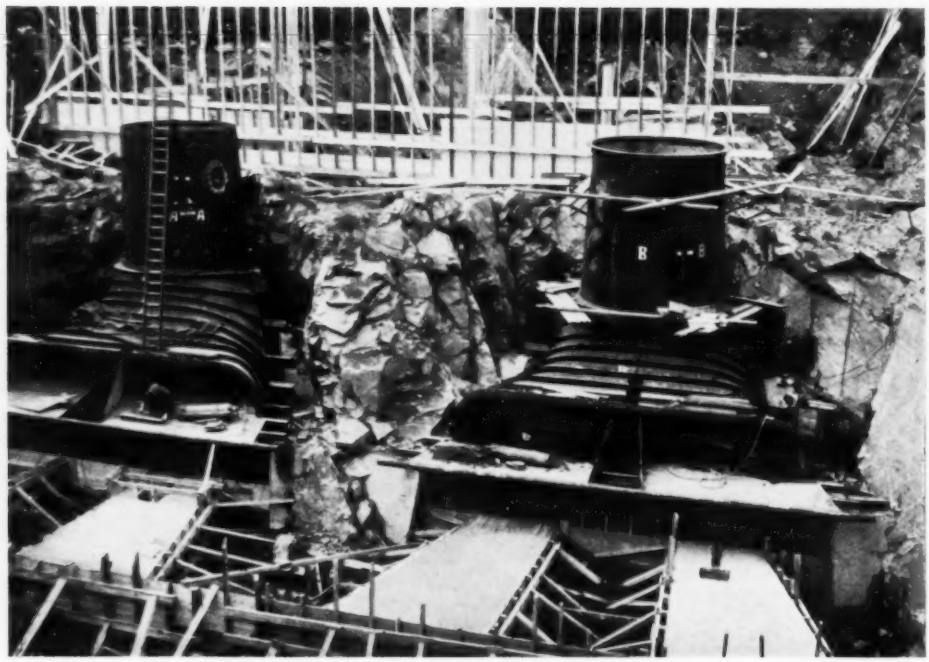


Fig. 35.—Draught Tubes in course of erection.
(By courtesy of the Galloway Water Power Company)

foot of the pedestals and are easily seen and operated.

TURBINES.

The turbine draught tubes are fabricated from mild steel plates by electro-welding, and consist of an upper taper pipe and an outflow bend, the latter portion being provided with a streamlined dividing wall built up of steel plates and beams, the purpose of which is to direct the water flow.

The draught tubes for this Station were manufactured by Sir William Arrol and Co., Ltd., and those for Carsfad and Earlstoun by the Whessoe Foundry and Engineering Co., Ltd., all being to the design of the English Electric Company.

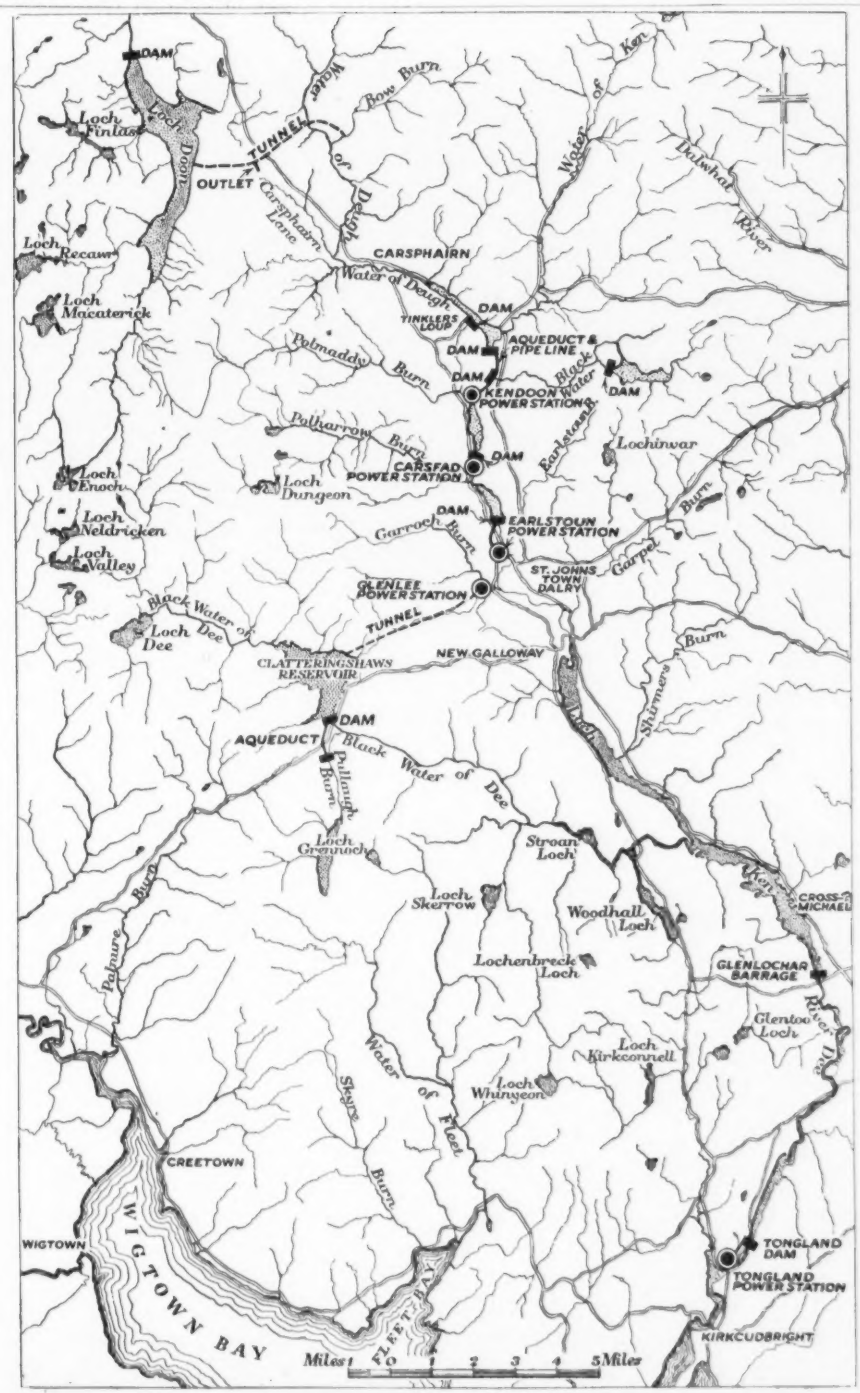
The design was very similar in every case and Fig. 34 shows two of the tubes assembled at the Works of Messrs. Whessoe Foundry and Engineering Co., Ltd.

They were sent to the sites in sections and there finally assembled in position and welded together, after which they were buried in concrete, strongly reinforced, in order to secure a solid foundation. Fig. 35 shows two draught tubes in course of erection on site, their size can be gauged by the man working in the exit mouth of the left-hand tube.

The turbine spiral casings have an inlet diameter of 9 ft. 6 in. and together with the generator supports, are fabricated from mild steel plates. Since in general design and construction they are very similar to those at Tongland which have already been fully described, there is no necessity to describe them here in detail.

There is, however, one important difference resulting from the fact that, at Kendoon Power Station, relief valves are provided for limiting the rise in pressure in the pipelines, the casings, therefore, have special branches on the opposite side to their inlets which convey the water to these valves and thence to the tail-race.

The relief valves are a very interesting feature of the Kendoon turbines, owing to their unusually large size, each being capable of discharging a maximum of about 30 tons of water per second. They are the largest yet built on the Company's streamline cylindrically balanced principle, having a 4 ft. 7 in. diameter bore and, since they are arranged to form a direct prolongation of the pipelines, the water is conveyed by the quickest and most direct route to the tail-race. By means of a simple mechanism, the valves open in synchronism with the closing of the turbine gates



Map showing locations of Power Stations and other works of the Galloway Water Power Scheme.

and the water is discharged in the form of a hollow cone which quickly loses its velocity in air friction and reaches the tail-race as a fine spray ; thus no damage is done to the tail-race or river bed. The main parts of the valve comprise an outer body, a piston of phosphor bronze, an inner body and the necessary control gear consisting of an oil dashpot, distributing valve, return motion gear and connection to the governor. Fig. 37 shows one of these relief valves on test at Rugby Works ; it will be noted that fabrication by welding has been largely employed in its construction. The interior of Kendoon Power Station during erection is shown in Fig. 36, the spiral casings can be seen in position on their foundations before being buried in concrete. The relief valve branches are clearly shown and the casing furthest away has its generator support in position. In the interior of the casing in the foreground it is just possible to see the stay vanes which form part of the cast steel speed-ring, and not only form a strong bridge between the upper and lower portions, but also guide the water into the turbine gate apparatus.

Fig. 38, which shows the interior of Earlstoun Power Station, illustrates a further stage in the erection. The spiral casings are completely buried in concrete and the generator pedestals are being built up around the steel generator supporting barrels. The pedestal furthest from the camera has been completed, and the shuttering and reinforcement rods for the nearer one are being placed in position in readiness for pouring the concrete.

The Kendoon turbine runner is 7 ft. 10 in. in diameter and consists of a one-piece steel casting with vanes carefully designed to ensure long life, and streamlined outlet edges. While every precaution is taken by most careful design to avoid cavitation, an additional safeguard is provided by giving the critical part of the vanes a coating of stainless steel applied by electro-welding. After this application the vanes are ground and polished to a perfectly smooth surface. The torque is transmitted from the runner to the shaft by means of a laid-in transversal key, the coupling bolts

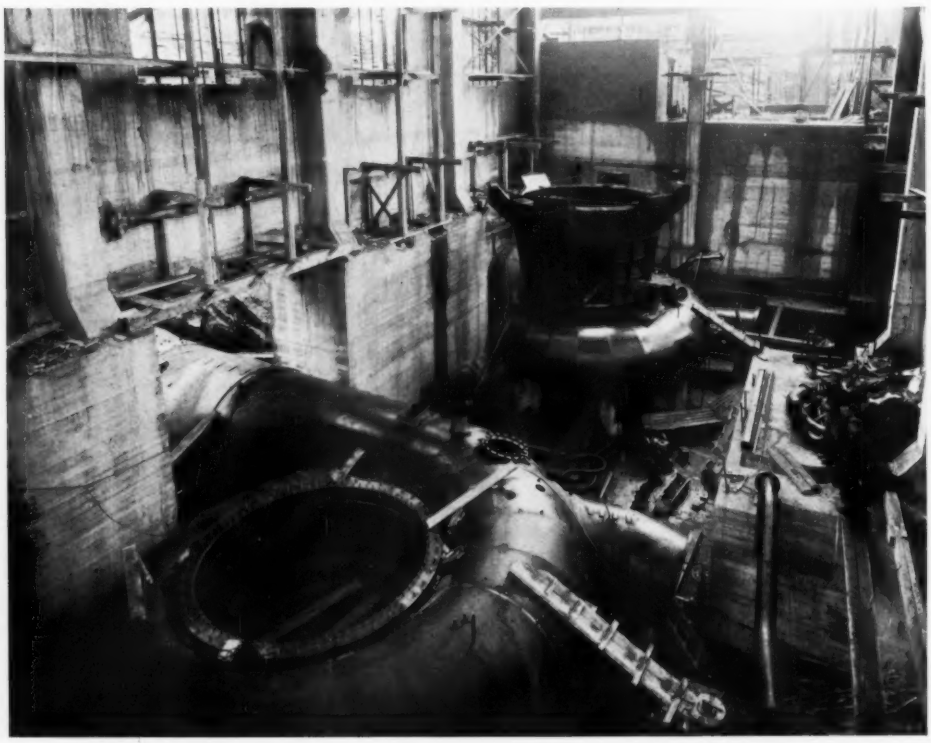


Fig. 36.—Erection of Spiral Casings and Generator Supports in Kendoon Power Station.

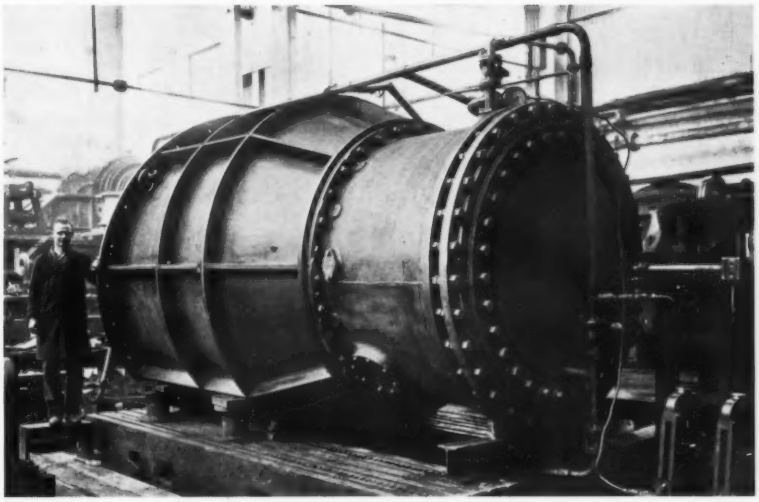


Fig. 37.—Kendoon Relief Valve on test at Rugby Works.

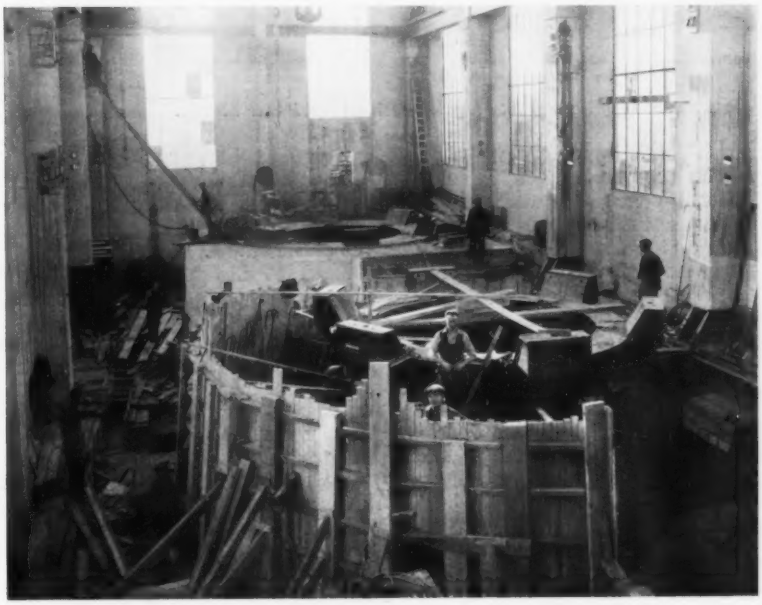


Fig. 38.—Generator Pedestals in course of erection at Earlstoun Power Station.

Fig. 39.—Turbine Runner being lowered into position at Kendoon Power Station.

being a clearance fit no reamering is necessary.

To give additional strength a steel ring is shrunk on the outer periphery of the runner wheel. Fig. 39 shows one of the Kendoon runners and shaft being lowered through the generator stator into position.

The turbine regulating mechanism, top cover, and oil-pressure governing system, are all very similar in design to those adopted for the turbines at Tongland Power Station, and have already been fully described and illustrated on pages 36, 37 and 38 of Vol. VIII, No. 2 of this Journal. They follow the Company's standard practice, and have been adopted throughout the Galloway scheme.

Generators.

If the cross section through the Kendoon unit (Fig. 33) is again referred to, it will be seen that the generator is of the umbrella type as adopted for Tongland Power Station. Although this design has been described in detail in an earlier article, it may not be amiss to repeat here its main principles.

For low and medium head plants where the combination of slow speed and flywheel effect are favourable, the umbrella construction for vertical shaft machines has considerable advantages. The design involves a rotor with drooping arms, which allows a combination guide and thrust bearing to be placed under the rotor hub close to the plane of the rotor rim.

With this combination the upper guide bearing is eliminated, the machine is lighter, there is no complicated system of oil pumps and piping, and the machine can be erected and dismantled in a lower head-room. An oil circulation system is not required, because the bearing design makes it possible to immerse both thrust and guide bearings in the same oil bath, the oil being cooled by water flowing through cooling coils.

The umbrella design is very simple to dismantle, as it is only necessary to disconnect the rotor from the shaft and to raise it to clear the top of the stator frame.

Each of the two generators at Kendoon is designed for a three-phase maximum continuous rating of 14,500 kVA., 0.8 power factor, 11,000-volts, 50 cycles at 250 r.p.m., with temperature rises not exceeding those specified in B.S.S. 226/1925. Each machine is also capable of supplying, for line charging purposes, approximately 50% of its kVA. rating at zero power factor with positive excitation at the slip rings.

To meet the requirements of the turbine the alternator rotor embodies a flywheel effect of 3.3×10^6 lbs. ft.^{2} (W.R.^{2}), and is designed for a runaway speed 95% above normal with a factor of safety not less than 3.5 based on the ultimate strength of the materials.

The general design and construction of the stator and thrust bearing follow on the lines

adopted and already described for the Tongland machines. The rotor is also generally similar with one important difference, the centre is of a robust fabricated construction instead of being cast.

The ventilation is on the closed-circuit principle as adopted for the whole of the eleven main generators comprised in the Galloway scheme. If Fig. 39 be again referred to, the six coolers round the periphery of the stator may be seen ready fitted and some of the sheet metal panels forming the outer casing, within which the air is circulated, are in position.

Fig. 40 shows the two Kendoon generator stators on site with coolers and sheet metal enclosures completely erected. Inside the machine in the foreground is the lower bracket ready to receive the rotor, and two of the Ferodo asbestos braking shoes, which bear against a brake track on the underside of the rotor, can be seen.

A study of Plate III in conjunction with Fig. 41 will give a good impression of the general layout of Kendoon Power Station. It will be noted that the switchgear, battery, etc. are contained in a separate annexe above the level of the turbine room floor and that the loading bay, which is served by the turbine-room crane, is also at a higher level.

The side elevation illustrates the block type design and it is evident that the massive concrete pedestal, which also forms part of the upstream wall of the Power Station, makes a very solid foundation for the unit and also acts as an anchor block for the bottom of the pipeline.

Fig. 41 shows the interior of the Kendoon Station and has been specially selected as it gives a clear view of the important auxiliary apparatus which the one-floor design renders particularly accessible.

In the foreground is one of the machine instrument and gauge panels, as adopted throughout the Galloway scheme, and upon it are mounted the lubricating oil-pressure and spiral casing water-pressure gauges, the draft tube vacuum gauge, the bearing temperature indicators, the ventilating air temperature indicator, the lubricating oil-pump contactor, the generator heater contactor, alarm relay, telephone, etc.

To the right of the panel may be seen the oil-pressure servomotor which operates the turbine regulating mechanism, and is controlled by the oil-pressure governor, which is mounted upon it. This is the English Electric Company's standard type of governor which together with the whole governing system, was described in detail in a previous issue. At the foot of the pedestal of the second unit is the governor oil-pressure receiver cylinder with electrically-driven oil pumping unit,

Fig. 40.—Kendoon Generator Station and Lower Bracket.

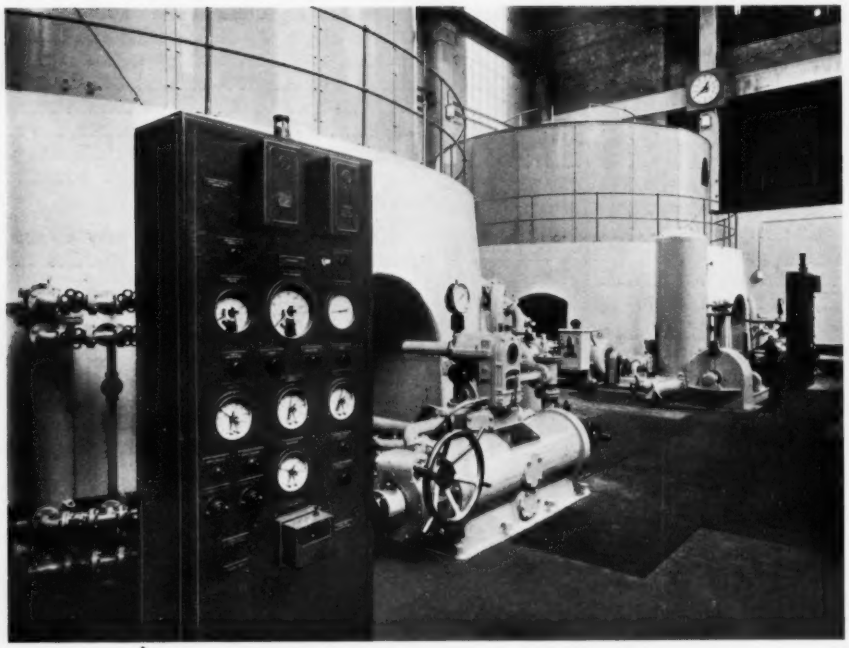
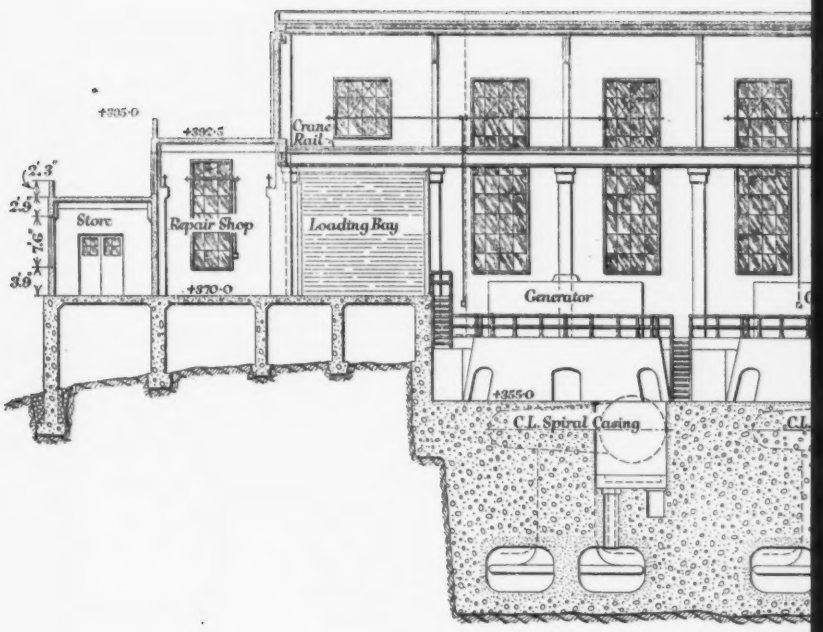


Fig. 41.—Interior of Kendoon Power Station containing two 6,000 kW. Water Turbine-driven Alternators.

Fig. 42.—Kendoon Power Station looking towards tail race.

THE GALLOWAY H

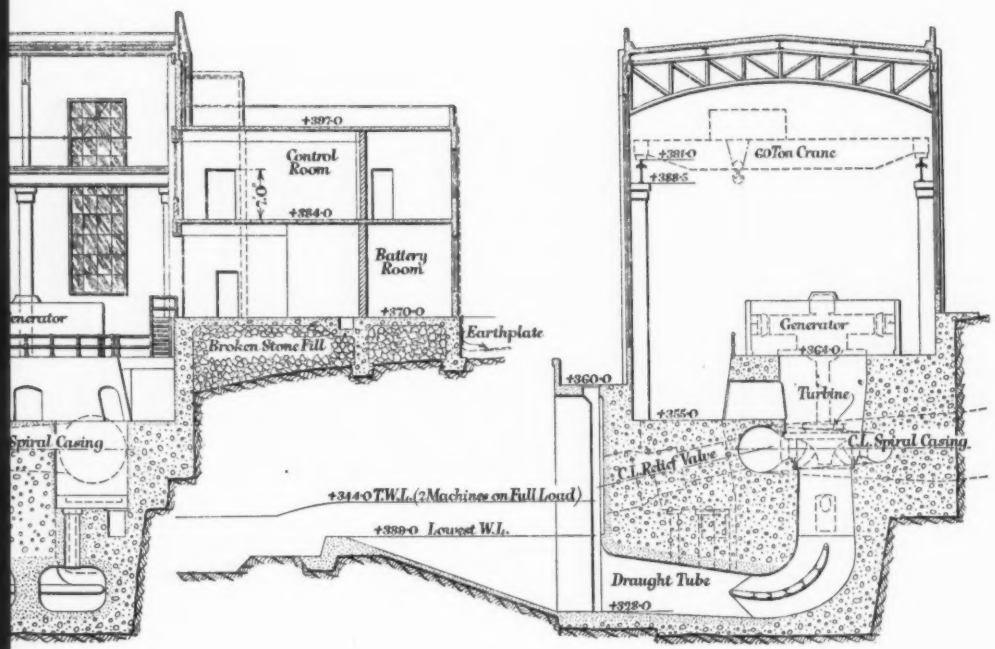
KENDOON



Cross Sections th

HYDRO-ELECTRIC SCHEME.

POWER STATION.



rough Kendoon Power Station.

and also a standby oil pumping unit consisting of a small impulse turbine driving a rotary pump.

An exterior view of the completed Kendoon Power Station, is shown by Fig. 42 ; the relief valve exits can be seen above the tail-race.

Earlstoun and Carsfad Power Stations.

The hydraulic conditions at Earlstoun and Carsfad Power Stations are practically identical, and consequently the four generating units in the two stations are almost exactly the same in design and construction. Each set consists of a vertical-shaft reaction water turbine of 9,200 h.p., working under a maximum head of 69 ft. and running at 214 r.p.m., driving a vertical-shaft three-phase alternator with a normal output of 6,000 kW. 7,500 kVA. at 0.8 power factor, 11,000 volts, 50 cycles, and a maximum output of 8,200 kVA. The generators have the same percentage line charging capacity as those at Kendoon.

The general design of the turbines at these stations is the same as that adopted at Kendoon with certain important exceptions. At Earlstoun and Carsfad there are no relief valves and due to the low head and different hydraulic conditions, the turbine runners are of the high speed or propeller type. These runners are 8 ft. 6 in. diameter over the vanes and Fig. 43 shows one of them at Rugby Works complete with shaft. It consists of a steel casting which when received from the founders, was provided with vanes having only part of the designed length.

End-pieces of the appropriate length and shape were made in forged stainless steel and were attached to the vanes by electro-welding after suitable preparation ; the whole was then ground and polished. By this means the most effective protection against cavitation was provided at the critical region.

The runner wheel is provided with brass sealing rings which are dovetailed and hammered into grooves. Balancing holes are made in the runner crown for the passage of any water that passes the seals.

The turbine spiral casings resemble closely those for Kendoon, but have a greater inlet diameter, namely 13 ft. 6 in.

The four generators installed at Earlstoun and Carsfad are of the umbrella type and though different in certain dimensions and running at a different speed, follow closely the design and construction of those at Kendoon. To satisfy the turbine requirements the flywheel effect (W.R.^{2}) of the rotating parts is 2.8×10^6 lbs. ft^2.

Fig. 44 shows one of the Carsfad Generator rotors being lowered into its stator. The weight of this rotor is about 50 tons.

Fig. 43—One of four 8,500 h.p. Propeller Wheels for Carsfad and Earlstoun Power Stations.

The layout of the Earlstoun and Carsfad turbine follows the general lines of the other Power Stations within the Galloway Scheme, as will be noted from Fig. 45, which shows the interior of the Earlstoun Station.

The Earlstoun and Carsfad plants are of outstanding interest, inasmuch as the starting up and shutting down of the generating units can be completely controlled from Glenlee Power Station. It is not possible, within the scope of the present article to describe in detail all the mechanical and electrical devices by means of which this automatic control is effected, but there will be found later a description of the principles of this control, of the sequence of operations and of the protective devices necessary for unattended stations.

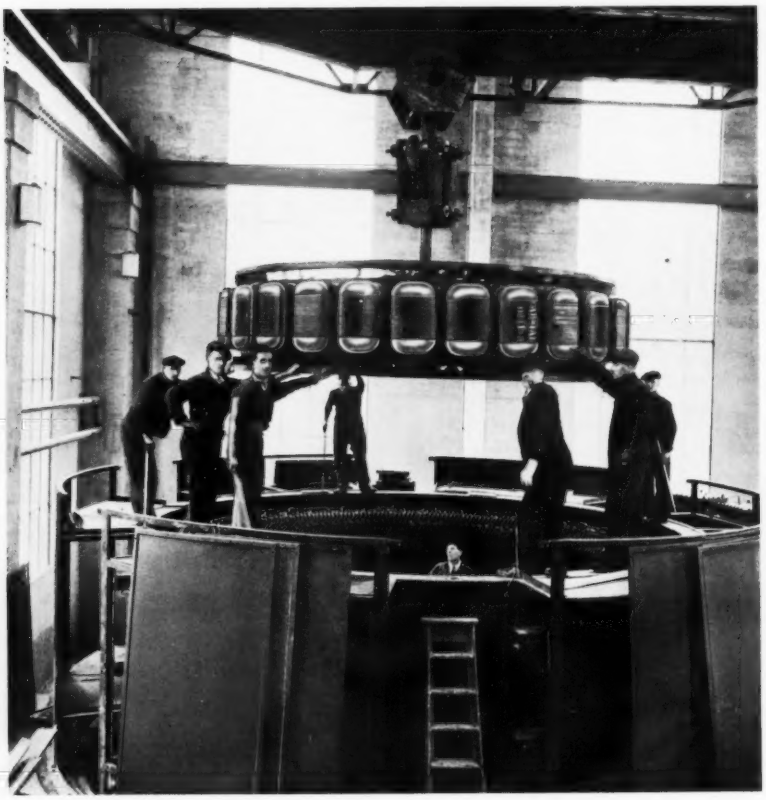


Fig. 44.—Carsfad Generator Rotor being lowered into Stator.

Main Switchgear.

The Switchgear at Earlstoun and Carsfad Power Stations consist of the main 11 kV switchgear, a control and relay board, an automatic voltage regulation and temperature indication board, 400-volt auxiliary switchgear, and 110-volt D.C. switchgear.

The 11 kV. switchgear is composed of metalclad pillars of the Company's O.L.E. type, with a breaking capacity of 250,000 kVA.

In construction they follow the well-known principles of horizontal draw-out metalclad switchgear, and represent the most up-to-date practice in this type of apparatus.

Fabrication plays a prominent part in the construction of the main frames, switch top-plates, tanks, and bus-bar and current transformer chambers. Automatic shutters and a full set of interlocks are provided.

All internal parts are accessible from the front of the board and such access is simple and convenient.

The circuit-breakers are solenoid operated, and are both locally and supervisory controlled. Their mechanisms are enclosed in such a way that the speed of opening is unaffected by pressure inside the tank. All circuit-breakers of similar type are interchangeable.

A lifting and transporting truck is provided for removing the circuit-breakers from their supporting frames, or tanks from circuit-breakers.

Duplicate busbars are provided for the generators and for one of the feeders.

The control and relay board for the 11 kV. switchgear consists of sheet steel cubicles with simplified mimic diagrams and semaphore indicators. It carries the local control switches, supervisory change-over switches, indicating lamps,

relays, and indicating and recording meters. Fig. 46 shows the control board at Carsfad Power Station.

The automatic voltage regulation and temperature indication board is also of the cubicle type and is equipped with automatic voltage regulators and field failure, no volt, and time delay relays. In addition, it carries the generator stator and rotor temperature indicators with their selector switches. The Carsfad board is shown in Fig. 47.

The 400-volt auxiliary switchgear consists of two interlocked circuit-breakers controlling the supplies from the Central Electricity Board and the station auxiliary transformers, the busbars being connected to outgoing high rupturing capacity fuse-switch units.

The switch pillars are of the O.L.A. flameproof type, solinoid operated with local and supervisory control. The fuse-switch units comprise an ironclad, air-break, quick-action switch with the fuse cartridge mounted on the blades ; these meet the most rigorous safety requirements for this class of apparatus and supply the turbine and alternator auxiliaries, station lighting, and heating, and battery charging.

Automatic Switchgear.

The generating units at Earlstoun and Carsfad Power Stations may be started up and shut down automatically from Glenlee Power Station by means of supervisory gear. In addition, they can be started up and shut down automatically by local electric control. Provision is also made for local emergency shutting down by the operation of push buttons mounted on the field suppression switch cubicle in the turbine room.

All the usual protective devices are embodied in the plant and control gear. The whole of the control gear at Glenlee, Earlstoun and Carsfad Power Stations for giving effect to the above operations, has been supplied by the Company or by their Sub-Contractors, the Automatic Electric Co., Ltd. Fig. 48 shows the automatic control

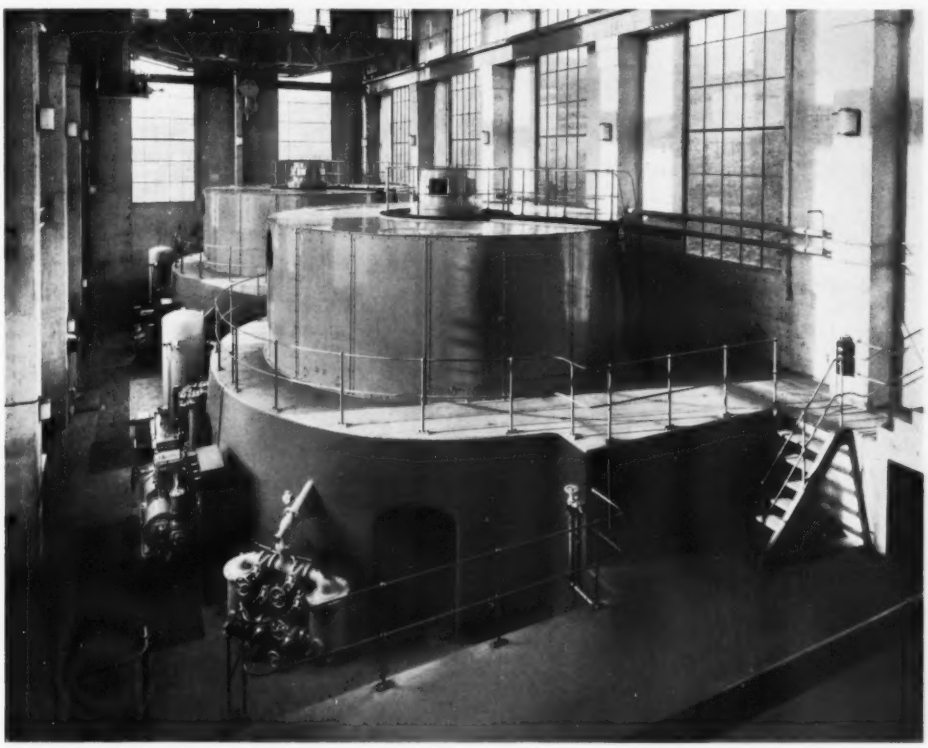


Fig. 45.—Interior of Earlstoun Power Station showing the two 6,000 kW. Water Turbine-driven Alternators.

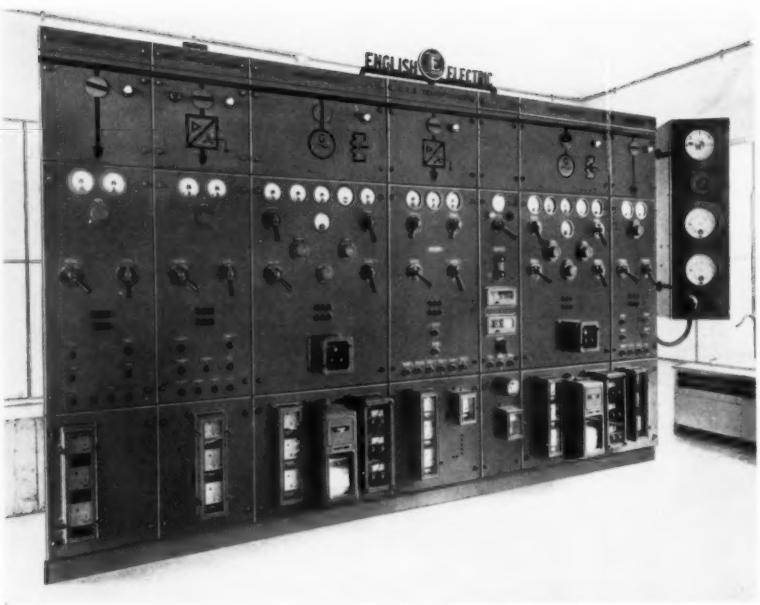


Fig. 46.—Control Board at Carsfad Power Station.

panels at Earlstoun Power Station, and next to them are the field suppression switch cubicles.

AUTOMATIC STARTING UP FROM GLENLEE.

Considering first the fully automatic starting up of the Earlstoun or Carsfad units from Glenlee Power Station, the following represents the sequence of operations :—

(1) The starting impulse is given over the supervisory gear from Glenlee and the master contactor closes.
(2) The governor oil pumping set is started and the governor oil valve is opened.
(3) When the governor oil valve is fully opened an electric motor starts to open the main sluice valve.
(4) When the main sluice valve is " crack open " the electric operating-motor stops.
(5) When the water pressure begins to build up in the spiral casing the motor-driven auxiliary oil pump starts.
(6) When the pressure has built up fully in the spiral casing, the sluice valve motor is restarted and fully opens the sluice valve.
(7) When the sluice valve is fully open the sluice valve operating-motor stops. The governor actuator solenoid is then energised and this begins to open the turbine gates.
(8) As the main turbine shaft revolves the gear-driven lubricating oil-pump builds up oil pressure and the auxiliary lubricating oil-pump stops.
(9) When the governor actuator takes over control, an oil-pressure relay operates and an indication is given at Glenlee via the supervisory gear. This is the final starting operation, and if previously selected, the automatic voltage regulator will be in control at this stage—also, at this stage, the synchronising set-up will be selected at Glenlee, thus providing control of speed and voltage via the supervisory gear.

The alternator can then be put on the line by closing the circuit-breaker from Glenlee Power Station, provided the field breaker is closed.

AUTOMATIC SHUTTING DOWN FROM GLENLEE.

The normal shutting down sequence from Glenlee is as follows :—

(1) The load is removed by the closure of the turbine gates by means of the electric-motor on the governor actuator.
(2) The operating motor is started in order to close the sluice valve.
(3) When the turbine gates reach the " no load " position the alternator oil circuit-breaker is tripped.
(4) The alternator brakes are applied at the end of a time delay which commences when the oil circuit-breaker is opened, the turbine gates closed, and the sluice valve closed.
(5) When the water pressure has practically disappeared in the spiral casing the governor oil valve is closed and the auxiliary lubricating oil-pump is shut down. The brakes are then released.
(6) When the governor oil valve is closed the governor oil-pressure pumping set is shut down.

If the shutting down impulse is given from Glenlee during the starting sequence, the shutting down operations follow the same sequence commencing at operation No. 2. When the inter-

ruption has been initiated, it is not possible to restart until the sluice valve and turbine gates have returned to the fully closed position.

The plant can also be shut down locally in the event of emergency by operating a control switch on an emergency control pillar situated in the turbine room and this trips simultaneously the alternator oil circuit breaker and the field breaker.

The normal starting sequence may also be interrupted locally at any stage by the operation of a control switch located in the control room.

Local Control, Starting Up and Shutting Down.

The plant may be started up and shut down by control at the Power Station itself, and the sequence of operations is exactly the same as that described above; the only difference being that the master contactor is energised by pressing a push-button switch at the Power Station instead of by an impulse given from Glenlee over the supervisory control.

Protective Devices.

Audible and visible indication is given at Glenlee Power Station via the supervisory gear, when the following conditions occur :—

(1) Loss of water pressure on discharge side of cooling water strainers.

(2) Excess temperature of any of the bearings.

(3) Auxiliary lubricating oil pump in operation.

The set is shut down in the manner tabulated above for normal sequence initiated from Glenlee in the event of :—

(1) Excess bearing temperature.

(2) Total starting time exceeding a pre-determined period.

(3) Loss of governor oil pressure.

(4) Loss of bearing oil pressure.

In addition to shutting down the set, audible and visible indication is given at Glenlee of the occurrence of any of the foregoing.

In the event of :—

(1) Overspeed,

(2) Loss of alternator field,

(3) Overload,

(4) Electrical fault in alternator winding,

(5) Over voltage,

the alternator is instantly disconnected from the line by the tripping of the alternator oil circuit-breaker and of the field breaker. At the same time the turbine is shut down in the normal sequence.

Further protection is also provided against the turbine gates being opened during starting operations and the turbine rotated while the alternator brakes are applied.

Audible and visible indication of all the above are also given at Glenlee via the supervisory gear.

Fig. 47.—Automatic Voltage Regulator and Temperature Indicator Board at Carsfad.

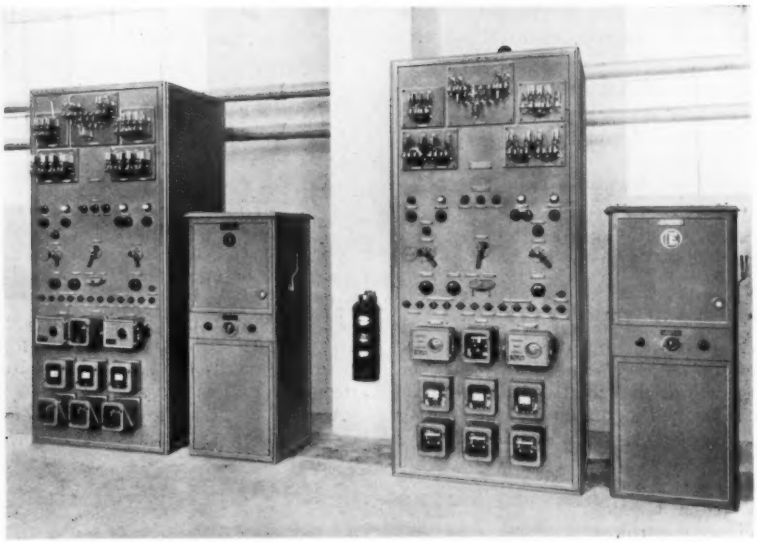


Fig. 48.—Automatic Control Panels and Alternator Field Suppression Switch Cubicles at Earlstoun.

Conclusion.

As already recorded, the plant at Tongland and Glenlee was put into commission with very little preliminary test and adjustment, but the plant at Earlstoun, Carsfad and Kendoon may be said to have done even better. When hydraulic plant is made ready for service, it is usually necessary to carry out quite a number of tests on the governing system, upon which the safety and satisfactory operations of the units so largely depend, and to make resulting adjustments.

Thanks to inherently sound design and the Company's policy of thoroughly testing their governors and allied apparatus at the Works before despatch, the time required at site has now been reduced to a minimum.

At Earlstoun and Kendoon Power Stations all load rejection tests, etc., were completed and the turbines were ready for service in the space of two days, and at Carsfad in only one day—a very satisfactory achievement.

Kendoon Power Station was put into commercial service on the Grid on the 26th October, 1936, and the two Automatic Stations, Earlstoun and Carsfad, went into service with full remote control from Glenlee on the 6th November, 1936.

The preliminary adjustments to the automatic equipments also occupied the minimum space of time and those equipments have operated very satisfactorily since they were commissioned.

In its engineering features the Galloway Water Power Scheme is one of the most interesting power undertakings in Great Britain, and it is gratifying that the English Electric Company has been able to make such an important contribution to its success.

The "English Electric" "Optimum" Blade for Steam Turbines of Large Outputs.

By F. J. COWLIN, A.M.I.Mar.E., Steam Turbine Dept.

The development of steam turbines capable of producing high efficiencies at the large outputs demanded by modern electricity supply undertakings has confronted the designer with a number of problems which have been solved only after much intensive analytical and experimental investigation. One of the most important of these problems, is the design of the last row of blades at the exhaust-end of the turbine where considerations of strength and efficiency have led to the introduction of the "English Electric" side-entry "Optimum blade." This article describes how this type of blading, illustrated in Figs. 5 and 6, has been developed from the experience gained with other forms and from a particular regard for the technical requirements of the case.

The efficiency of a steam turbine, in common with all other steam engines, is measured by comparing the amount of heat which it usefully employs, with the amount of heat available to a perfect steam engine operating on the Rankine cycle.

The maximum efficiency obtainable is given by the following expression :—

$$N = \frac{H_1 - H_2}{H_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where H_1 = total heat of the steam at the initial pressure and temperature.

H_2 = total heat of the steam at the exhaust pressure and temperature.

N = Efficiency.

It will be noted from (1) that the efficiency can be increased by obtaining a greater value of H_1, by reducing the value of H_2, or by a combination of both alternatives.

The modern tendency to use higher initial steam pressures and temperatures has the effect of raising H_1 and the increases in turbine and power station efficiency which can be obtained in this way have been dealt with very fully by Law and Chittenden.* The conditions selected have a direct bearing, however, on the design of the exhaust-end of the machine since the total temperature adopted for any particular pressure mainly determines the wetness of the steam at the exhaust.

A reduction in H_2 is only possible by working with a higher vacuum and the gains which can be obtained in this way are well established. The specific volume of the steam increases rapidly, however, with increase in vacuum as shown in Fig. 1, the upper curve of which gives specific

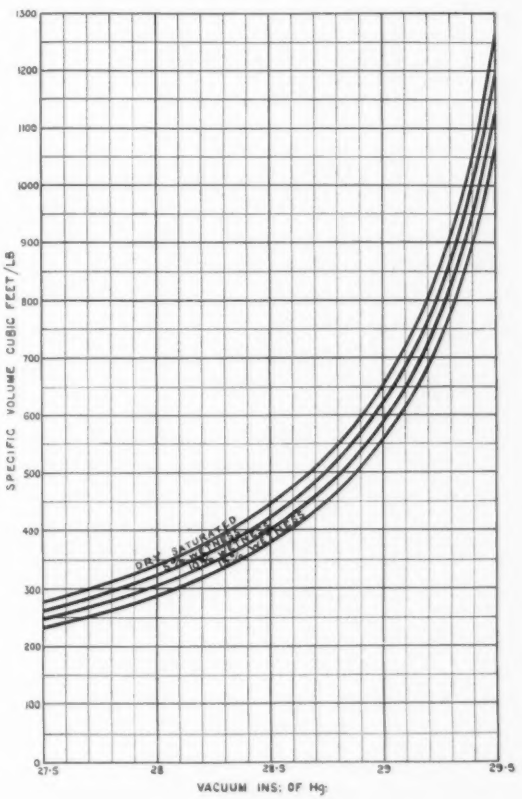


Fig. 1.—Specific volume of steam with varying vacua.

* "*Higher Steam Pressures and Their Application to the Steam Turbine*," *read before the I.E.E. in London, November 3rd*, 1927.

volumes of dry saturated steam and the lower curves the volumes with different degrees of wetness, which vary between 10 and 14% under modern conditions.

The reduction in volume with wet steam is directly proportional to the percentage wetness but even when this is allowed for, large volumes of steam have to pass through the last stage blades, the total volume being obtained as follows, if steam extracted for feed heating purposes is excluded :—

$$V = \frac{3412 \text{ kW.} \times v}{N \times H} \quad \ldots\ldots (1)$$

where V = Total volume.
kW. = Output in kW. at turbine coupling.
v = Specific volume at any particular stage.
N = Overall efficiency (turbine only).
H = Heat drop between initial and final conditions.

The area through the blades is given by the equation :—

$$A = \pi \, Dh \sin \alpha \, f, \text{ first approximation} \quad (2)$$

where A = Area.
D = Mean dia. of blades.
h = Blade height.
α = Blade angle.
f = Correction factor for blade thickness.

and from the conditions of continuous flow :—

$$V = AC_0 \quad \ldots\ldots (3)$$

where C_0 = Steam speed.

therefore $V = Dh \times \pi \sin \alpha \, f \, C_0 \quad \ldots\ldots (4)$

In this expression f is fixed by manufacturing requirements and sin α and C_0 tend to a minimum for conditions of maximum efficiency so that with any fixed value of V an increase in efficiency involves increases in D and h and with any fixed efficiency conditions larger values of V also necessitate increases in D and h.

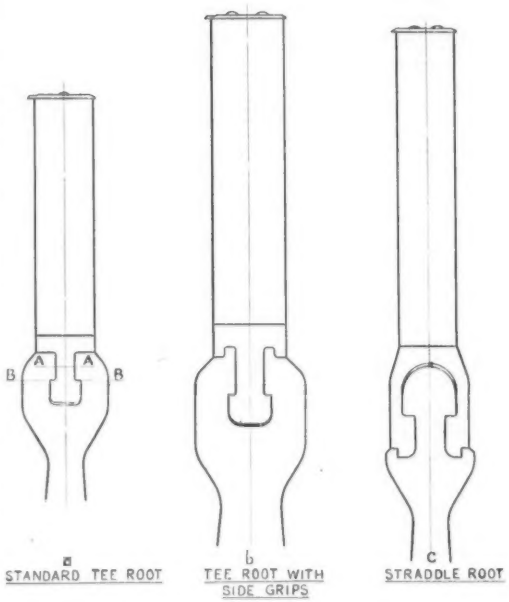


Fig. 3.

It will be seen also from (1) that with fixed steam conditions and turbine efficiency the total volume V is directly proportional to the output.

Both the output and efficiency of a large steam turbine are, therefore, governed by the limiting values which it is possible to adopt for the diameter of the last wheel and the height of the last blade consistent with the safe stresses allowable for the materials used, the approximate maximum outputs at 3,000 r.p.m., with various sizes of wheels and different vacua, being shown graphically in Fig. 2.

The method of computing the stresses in a rotating disc has been previously dealt with in this Journal,* and particular attention is drawn to the influence

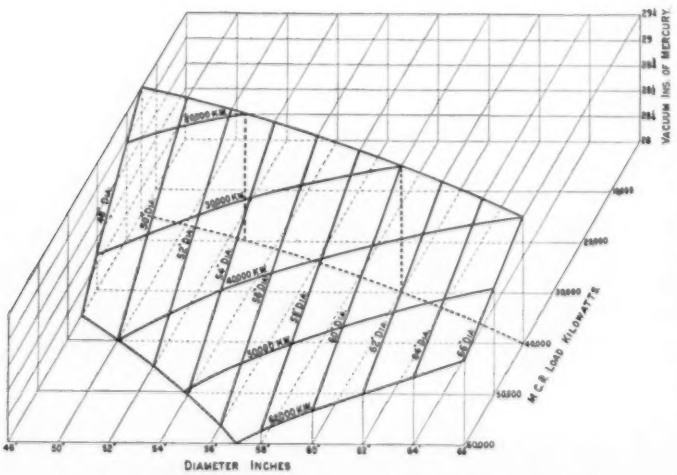


Fig. 2.—Approximate maximum turbine outputs at 3,000 r.p.m

* "*Determination of Turbine Disc Stresses,*" *by S. J. Moyes* (*Vol. VIII, No.* 4). *December,* 1936.

which the superimposed loading due to the disc head and blading, has on these stresses.

Disc head design is intimately bound up with the type of blade attachment adopted and any type of attachment which enables a lighter disc head to be used whilst maintaining equal reliability, will result in a reduction of the disc stresses or alternatively in the employment of larger discs, or longer blades.

It has always been the practice of The English Electric Company to adopt a mechanical type of blade attachment, thus eliminating the variable factors produced by hand labour where the type of attachment involves either riveting or caulking. The Company's standard Tee root, which is illustrated in Fig. 3*a*, is an established feature of their turbines, and one that has been employed by them over a period covering some fifteen years. The blades are milled from rectangular bar of material selected with particular regard to its suitability for the duty required, mechanical, chemical, and magnetic tests being used to ensure that no faulty material is included. Descriptions of these tests and the apparatus used have already been described in this Journal* and particular care is exercised throughout the various stages of manufacture to ensure that any defective material is rejected.

For blades of normal length this Tee root design is entirely satisfactory, but it was found as larger units were developed and longer blades became necessary, that the shoulder and bending stresses increased to such an extent that the size of disc head required, unduly increased the stresses in the disc and at the same time tended to prejudice the design of the adjacent blading.

The method of attachment was consequently strengthened by the provision of side grips as illustrated in Fig. 3*b*. These provide suitable restraint to deformation of the disc head and materially reduce the bending stresses on the jaws, thus enabling longer blades to be used without increasing the size of the head or the stresses due to the superimposed loading on the disc.

An inverted form of the Tee root with side grips known as the "Straddle Fixing" is illustrated in Fig. 3*c* and this enabled still longer blades to be used as it will be noticed that the inversion reduces the weight of the disc head whilst at the same time retaining the best features of the previous designs.

Demands for still larger units, however, soon made it essential to produce further improvements and led to the introduction of the "English Electric" "Optimum" side-entry blade and attachment. Fig. 4 shows a section through the blade and root in a plane at right angles to the shaft axis together with a plan view, whilst Figs. 5 and 6 reproduce respectively a photograph of an actual blade and a portion of the disc rim with several blades in position.

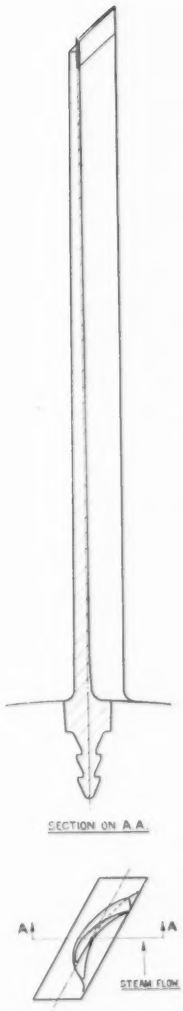


Fig. 4.—Section and Plan of Side-entry Blade.

The blade root is provided with multiple shoulders arranged in a tapered formation so that the shoulder loading is spread over a large area, whilst the section on which the centrifugal load is carried is also a maximum, both of these advantages being increased by positioning the root at an angle to the plane of the disc so that the

* "*Steam Turbine Research at Rugby Works*," *by J. P. Chittenden.* (*Vol. VIII, No.* 6).

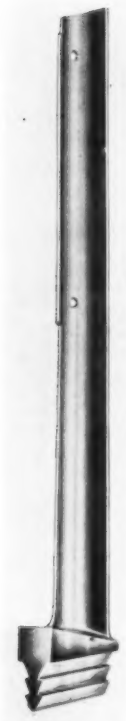


Fig. 5.—Side-entry Blade for last L.P. stage of 3,000 r.p.m. Turbine.

centrifugal load from the blade is symmetrically disposed in relation to the root, and bending stresses in the blade are eliminated. It also allows the blades to be more closely spaced than would be possible if the root was at right angles to the disc, thus enabling the most efficient steam path to be provided and at the same time giving a slightly longer width of root.

Bending stresses in the jaws of the disc head occurring in previous designs are also completely eliminated by the side-entry construction with the result that the additional disc stresses due to blade and disc head loading are considerably reduced. A further reduction is obtained by tapering the blade from root to tip so that the section at any point is in proportion to the centrifugal loading which it has to carry and the total weight of the blading is a minimum. It will also be noted that the inlet blade angles are varied along the blade length so that the steam may enter without shock. This variable angle is essential with long blades since the ratio blade speed/steam speed cannot remain constant, the steam speed being the same from root to tip, whilst the blade speed varies.

The angular disposition of the blade root to the disc also ensures that the pressure from the change in momentum of the steam during its passage through the blade is practically at right angles to the axis of the root and there is consequently very little tendency for the blades to be displaced axially. To prevent any such movement, however, the blades are finally locked into position by lightly peaning the blade root into a small circumferential groove turned in each face of the disc rim as shown in Fig. 6.

The general construction of the complete rotor is shown in Fig. 7 which illustrates a low-pressure rotor for a two-cylinder turbine with side-entry blades in the last two stages mounted in the

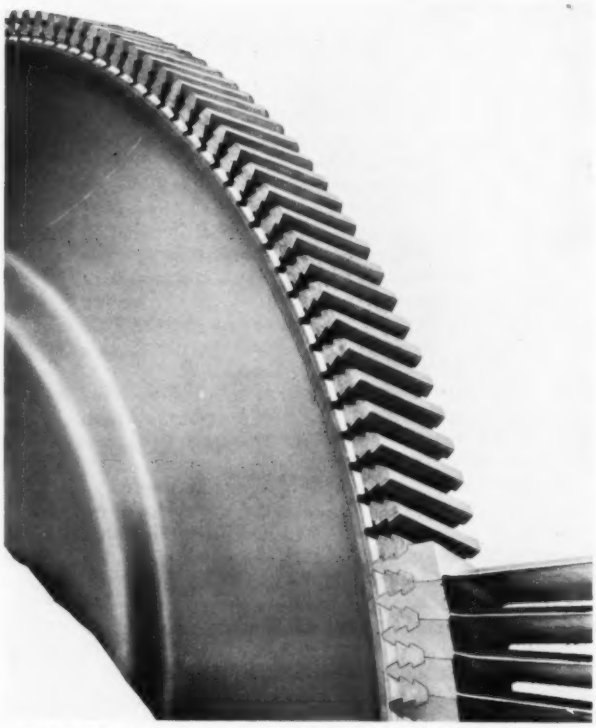


Fig. 6.—Part of Turbine Disc showing Side-entry Blade Slots and Blades in position.

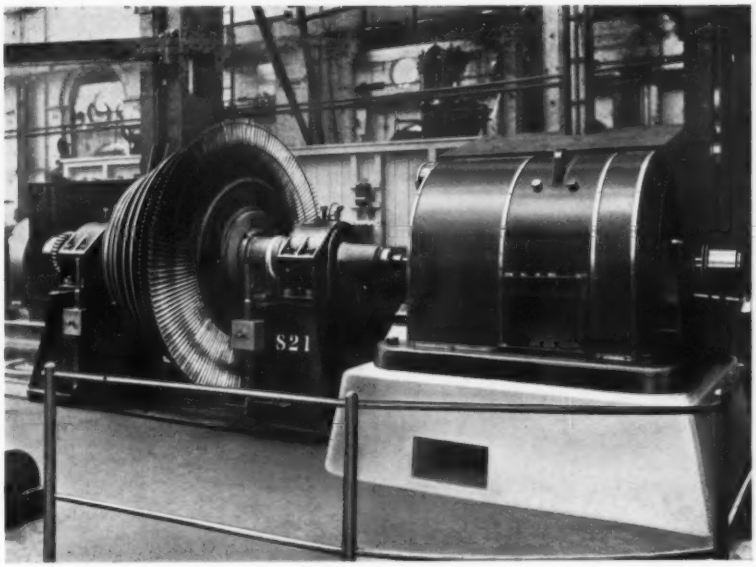


Fig. 7—3,000 r.p.m. Low-Pressure Rotor for two-cylinder Steam Turbine in the Dynamic Balancing Machine at Rugby Works.

dynamic balancing machine at Rugby Works.

The balancing operations are carried out at a comparatively high speed, thus enabling the smallest out-of-balance forces or couples, which might produce bad running conditions, to be detected and eliminated.

Railway Electrification in Poland.

(*Concluded from page 245, Vol. VIII, No. 7.*)

Substations and Track Sectioning Cabins—(*continued*).

Smoothing equipment is provided with each rectifier. It comprises a series reactor in the cathode lead and four resonant circuits connected between the positive and negative poles of the rectifier unit. The four resonant circuits each consist of a condenser and small reactor tuned to resonance at 300, 600, 900 and 1,200 cycles respectively, and protected by high rupturing capacity fuses. These circuits may be seen in Fig. 5 (page 245, Vol. VIII, No. 7) on the gallery to the left of the small recooler. With the smoothing equipment in operation, the r.m.s. value of the voltage ripple is less than 1½ per cent. of the normal D.C. voltage.

Supply for the various substation auxiliaries, heating and lighting, is obtained from auxiliary transformers connected through outdoor fuses to the 35,000-volt network, and from a substation battery.

Control of the substations is effected manually in the case of substation 3, but remote and local control is provided for all other substations. Substation 4 is controlled from substation 3 by remote control equipment of the code selector type, operating over two telephone pairs, and the remaining substations are controlled over multicore cables from the nearest railway station.

The remote control facilities include control and indication of all substation breakers and rectifiers, indication of lockout conditions, meter readings and telephonic communications. In

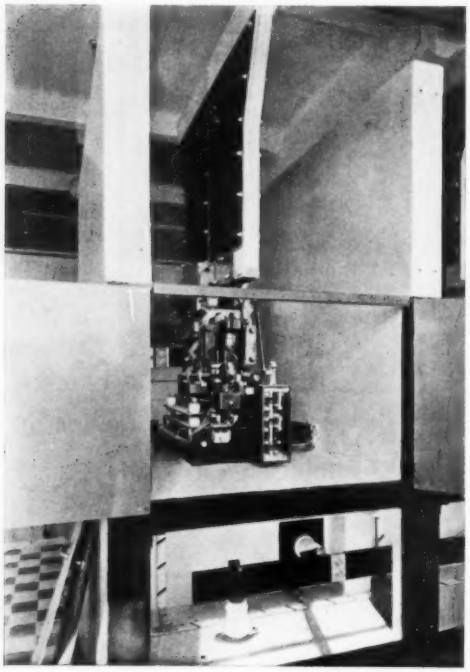


Fig. 6.—High Speed Circuit-Breaker in its Cubicle.

addition, the substations are provided with all necessary protective apparatus for shutting down equipment in the event of a fault.

In each of the six track sectioning cabins, the incoming lines from the catenary are connected to a common 3,300 volt bus bar through high speed breakers, arranged for forward tripping only. The fully automatic reclosing equipment is arranged for operation from the 3,300 volt incoming lines, thereby eliminating the necessity of control batteries and charging gear in the track cabins. Fig. 6 depicts a high speed circuit-breaker mounted in its cubicle, and is typical of all the high speed breakers used on the system.

Overhead Equipment.

The overhead equipment has been carried out by British Insulated Cables, Ltd., Prescot, under a sub-contract including the design, supply and erection of all material necessary to convey power from the direct current bus bars in the various substations to the pantagraph collectors on the trains together with the bonding of the earth return and structures.

The main line overhead equipment consists of two 100 sq. mm. hard-drawn copper grooved contact wires, alternately suspended by flexible droppers from a 19/.083 in. cadmium copper catenary. The catenary is supported and the contact wires registered in position from a galvanised tee-bar and tie rod cantilever fixed on insulators which are carried on a steel supporting mast. At the end of each tension or drum length the catenary and contacts are brought to a common yoke and tensioned by cast iron balance weights mounted on the mast. The load is transferred by a galvanised steel chain passing over ball-bearing pulleys. The arrangement is shown in Fig. 7.

There is a mid point anchoring arrangement at the centre of the tension length and the inter-

Fig. 7.—Overhead Line Equipment—Bracket Arm Construction and Tensioning Weight.

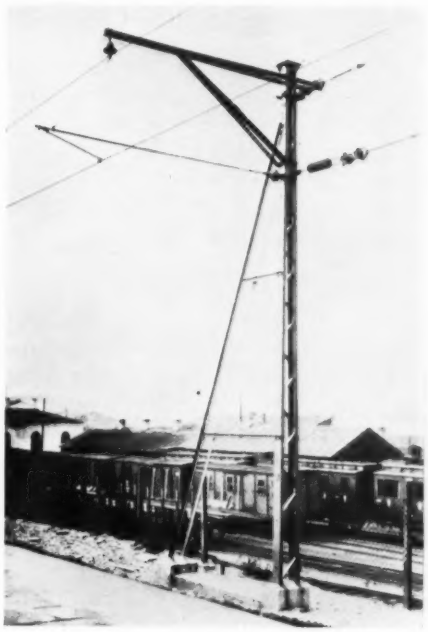


Fig. 8.—Fixed Catenary and Single Contact Wire used in Sidings and Junctions.

mediate cantilever supports swing as a gate with movement of the equipment due to changes of temperature. A uniform tension is thus maintained in the conductors irrespective of the temperature change. The "up" and "down" lines are kept mechanically independent. The normal span length is 72 metres for tangent track, and where necessary on curves, the span length is shortened or "pull-offs" introduced to give the correct registration of the contact wire.

For tangent tracts the contact wire is normally staggered 30 cms. from the centre of the pantagraph in opposite directions at adjacent supports, the wires being central on the pantagraph at the mid point of the span. On curves the registration of the contact wires at each support is carefully regulated to give the best conditions against the possibility of a "blow-off" in the centre of the span.

The normal tension length is 1,200 metres and before each wire is turned out for anchoring on a mast, the contact wires are kept in parallel running for a short distance to ensure a smooth transition of the pantagraph from one tension length to the next. No mechanical splices are used in the contact wire, and as far as possible the line is adjusted to give uniform flexibility.

In sidings and junctions it is desirable to keep the equipment as simple as possible, and for this reason, a system using a fixed catenary and a single contact wire terminating with steel com pression springs has been adopted, as shown in Fig. 8.

The line passes from Warsaw Central through a tunnel approximately 1,200 metres long, then over a viaduct and the Vistula bridge to Warsaw East. The type of equipment adopted for the tunnel, where the clearances are very limited, is a fixed catenary, supporting two alternately suspended contact wires, which are anchored by springs at each end of the tunnel. The catenaries are supported from cross spans and as far

Fig. 9.—Overhead Line Equipment—Typical Station Construction.

as possible, all insulation is kept away from the direct blast of steam locomotives.

The normal supporting masts consist of two No. 12 channels with riveted strip bracing as illustrated in Fig. 7, but on the Minsk line the masts have welded batten plates. In junctions and for special work, light fabricated bridges have been used and for multiple track work cross span construction has been adopted, giving a "clean" appearance, as, for instance, in the station layout shown in Fig. 9.

All steelwork and a considerable proportion of the overhead copper has been manufactured and supplied in Poland. The work of installing the foundations has also been carried out by Polish sub-contractors, and normally consist of a concrete foundation in which a cored hole is left for the reception of the steel masts. The masts are grouted in these holes after erection. In Warsaw East and Warsaw West, where cross span construction is used, foundation bolts are installed with the foundations.

Single disc type insulators have been used for the supports and the insulation between tracks in junction work. Double insulation has been used for all terminating insulators, switch insulators and section insulators.

The fittings have, as far as possible, been made of non-ferrous material, but where ferrous, they have been galvanised. The switches are of a robust knife type mounted on the masts and operated from ground level. They are not designed to break under load, as the normal protection of the overhead line, in case of a fault, is afforded by the high speed breakers in the track sectioning cabins and substations.

The connection between the substations, track sectioning cabins and the overhead line is by means of paper-insulated lead-covered armoured cables. A lightning arrester is mounted on the overhead equipment at each feeder position.

All rail joints are bonded with a flexible copper bond, electrically welded to the rails. The structures are normally connected by a copper earth wire, and where automatic signalling is used or proposed, connections are taken from the structure to the neutral point of impedance bonds; otherwise frequent cross bonds and bonds to traction return rails are used. At special points, such as the tunnel, the Vistula bridge, and certain overhead bridges, spark gaps have been used to connect between the structures and the rails.

Each section of the overhead line, when completed, is pressure tested at 9,000 volts for two hours, i.e., three times normal working voltage, and all feeder cables are pressure tested to British Standard Specification.

Multiple Unit Stock.

The suburban traffic will be served in the first instance by 76 train sets, each consisting of a motor coach and two trailers, the latter coaches being articulated together through a common bogie. There is seating accommodation for 80 passengers in the motor coach, 93 in the non-driving trailer and 99 in the driving trailer; these figures include a number of tip-up seats in the vestibule and luggage compartments. All coaches have lavatory accommodation and there is a luggage compartment adjacent to that containing the control gear in the motor coach.

The motive power is derived from four 200 h.p. traction motors all of which are mounted on the axles of the motor coach. The control equipment is coach-mounted in a special compartment, while the auxiliary machines and main starting resistances are carried on the underframe.

The traction motors are of the coach-ventilated series wound type with two stages of weak field control. Although insulated for full line voltage they operate two in permanent series each at 1,500 volts and have ratings in accordance with B.S.S. 173 for class B insulation as follows :—

Traction Motors—Multiple Unit Stock.

Self ventilating through coach. Field control : 100%, 70%, 56%. Gear ratio 74/21. Wheel diameter, 1,000 m.m.

			At full field.	
Rating.	H.P.	Volts.	Tractive effort Kg.	Speed Km./hr.
Cont.	144	1,500	760	52.3
1-hour	200	1,500	1,250	44.2

The transmission between motors and wheels is through straight spur gearing having a ratio of 74/21, the gears being housed in fabricated steel cases.

Fig. 10.—One of the Multiple Unit Trains.

The armature rotates in roller bearings while the frame is suspended in the usual manner by sleeve bearings on the axle, and a resilient block supporting the nose. An earth brush is also provided between the motor frame and the wheel axle.

Though the motors are of the usual self-ventilating type, the air is drawn through louvres in the sides of the coach body connecting with the motor frames by ducts and flexible bellows.

Current is drawn from the overhead contact wires by a pantagraph of the single-pan type identical with those of the locomotive. Two pantagraphs are mounted on each motor coach and interconnection or isolation is effected by means of pole operated isolating links. A small hand operated pump is used for raising the pantagraph in the event of the air reservoirs being exhausted.

The main circuit continues through a main power fuse of the cartridge type enclosed in a fire-proof box, and through a choke coil which in conjunction with a condenser type lightning arrester provides the necessary surge and lightning protection.

The control gear is mounted on two removable frames in separate compartments, the doors of which are interlocked to prevent opening when the apparatus is alive. To facilitate removal all interconnecting cables are taken to terminal boards, while the coach body is provided with suitable doors through which the frames may be withdrawn. One frame carries the main high tension control gear, the other houses control apparatus for the auxiliary and control circuits.

The system of control is of the "English Electric" motor-operated camshaft controller type suitable for multiple-unit operation.

The general scheme of control provides that apart from transition, no current is broken in any part of the apparatus except in the line breakers, of which there are four arranged to open in two stages, the first set inserting a resistance, which has the effect of limiting the current, the second set finally rupturing that current. The line breakers and reverser are electro-pneumatically operated.

The series-parallel grouping of the motors, cutting out of the resistance steps and the stages

of field control are carried out by the camshaft controller, which ensures positive mechanical sequence and thus eliminates a number of electrical interlocks that would otherwise be necessary.

The main starting resistance is of the continuous strip light-weight unbreakable type and is mounted on the underframe with double insulation.

The movement of the train is governed by a master controller which is provided with the usual mechanical interlocks and with a dead-man's button device. Provision is made for manual or automatic acceleration in the forward direction under the control of a current limit relay, but in reverse only manual control is available.

The control circuit is at 110 volts and this is energised by a 10 kW. motor generator set mounted beneath the car body. The motor runs directly off the 3,000 volt line and is controlled by a remote-operated contactor of the electro-magnetic type while the generator output is governed by a voltage regulator.

For emergency operation of the control circuit compressor and emergency lighting, a nickel iron type battery of 73 cells is provided, which normally floats across the low tension side of the motor-generator set, and is protected by the usual cut-out devices.

The apparatus controlling the motor-generator set and battery circuits is mounted on a panel which is accessible from the driver's compartment The remaining auxiliary circuits are also controlled from this panel and comprise the motor-compressor circuits and the lighting and heating of the train.

The braking system is of the Westinghouse electro-pneumatic type and air is supplied from a 110-volt motor driven compressor unit. The motor is started up through one step of resistance which is automatically cut out as the speed rises.

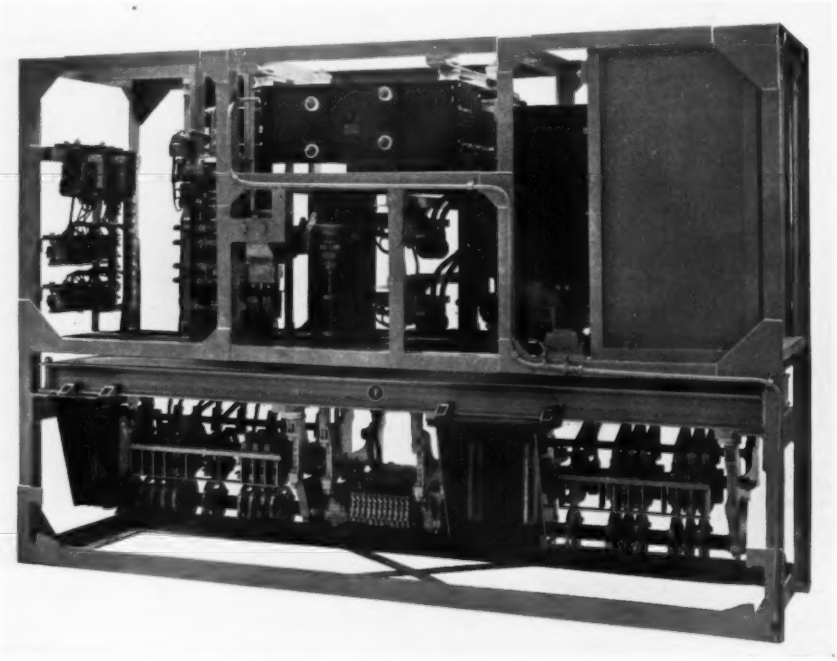


Fig. 11.—Auxiliary and High Tension Compartment of the Motor Coach.

The compressor also provides power to operate door closing and opening gear, which is under the control of the driver. Contacts are provided on the master controller to ensure that power cannot be applied to the motors until all the doors have been closed and the brakes released.

The normal lighting supply is derived from the motor-generator set at a tension of 110 volts, two circuits being provided through the length of the train, each controlled by a remote-controlled electro-magnetic contactor.

Coach heating is carried out by means of heaters mounted on the coach floor. Each heater is rated at 700 watts, 28 of these being carried on each motor coach and 32 on each trailer coach. The heaters are arranged in banks of 4 in series across the 3,000 volt bus-line. Two circuits are provided through the train lengths, each under the control of an electro-magnetic contactor; one circuit, affording roughly half the total heating, is switch controlled, the other circuit is arranged for thermostatic control.

The control wires and bus lines between coaches are taken to roof-mounted connection boxes which are joined by semi-permanent jumpers. Suitable jumpers, plugs and sockets are supplied at the two ends of the 3-coach train to permit of multiple-unit operation, but no provision is made for interconnecting the train units for heating purposes, each 3-coach unit being considered self-contained in this respect.

In addition to the master controller and E.P. brake valve, the driver's cab equipment includes sundry control switches and one or two low tension indicating instruments, together with a speed indicator. A window heater as well as a cab heater is provided in the driver's compartment.

Locomotives.

The locomotives are to be used for passenger services and also for hauling freight trains through the tunnel section. They are of 2,200 h.p. rating and each locomotive weighs 78 tons. The construction is of the B + B type, the body being carried upon a pair of bogies each with two driving axles. The bogies, which have a wheel base of 9 ft. 3 ins. each, and coupled together by an articulated joint which is designed to transmit the draw-bar pull without imposing any strain upon the locomotive body. The joint allows the bogies to swivel freely, and to angle and rise vertically to one another when traversing the curves and grades. The joint has no lateral play, and thus constrains the bogies on curves in such a way as to minimise and equalise the tyre wear.

The body is a single structure of 40 ft. long, 9 ft. 6 ins. wide, and is divided into five main compartments all connected by a corridor on one side of the locomotive. These compartments comprise the driver's cab at either end, one chamber for high-tension gear and resistances, and two auxiliary machine chambers. The high-tension chamber is in the middle of the locomotive, and access to this chamber can only be obtained through a sliding door which is electrically interlocked.

Each axle is driven by a 550 h.p. series wound interpole, axle mounted, nose suspended motor, operating through a resilient gear.

The main characteristics of the motor are as follows :—

Traction Motor Particulars—Locomotives.

Forced Ventilated. Gear Ratio 22/69.
Field Control —4 steps. Wheel Dia. 1,220 mm. (48 ins.)

Rating.	H.P.	Voltage.	Tractive Effort in Kgs. (full field).	Speed (Kms./hr.)
Continuous	450	1,500	7,200	68
1 Hour	550	1,500	9,500	64

The motors are forced ventilated by means of blowers, one for each pair of motors, situated immediately above them, and delivering air through flexible ducts into the motor frame, where it divides into two paths, one through the armature and the other through the field system. The circulation is assisted by fans mounted on the armature.

The motors are wound for 1,500 volts, insulated for full line voltage of 3,000 volts, and are permanently connected two in series. The control circuit is arranged for two combinations, namely, one circuit of four motors in series, and two circuits of two motors in series.

Fig. 12.—One of the Locomotives.

Situated on the roof are two pantagraphs, air operated and spring controlled. The pantagraph is of light but strong and rigid construction. It is raised by an air piston, and operates so that in raising the pantagraph is caused to rise rapidly through the first part of its movement, but slowly through the last stages, so as to obviate " bouncing " on the wire. The single collecting pan is mounted in a special manner, so that uniform horizontal position is maintained as the pantagraph follows variations in the height of the contact wire, irrespective of the position of the point of pressure on the pan.

Other items of roof equipment are pantagraph isolating switches, fuses, lightning arrester and choke coils.

The high-tension compartment houses the contactors and resistances for controlling the main motors, and also the high voltage control for the auxiliary equipment. To ensure safety, the compartment is specially locked, and can only be unlocked by the use of the reverse key of the master controller. Furthermore, even with this key, the high-tension chamber cannot be unlocked until the pantagraph has been dropped, removing completely all contact with the 3,000 volt overhead line system.

Two machine compartments contain the motor generator blower set, which consists of a 3,000 volt motor operating a 110 volt generator, which gives energy for the control circuits, lighting and auxiliary services, together with energy for the compressor motor, which supplies compressed air for the brake system and the operation of the electrical contactors. The set also operates the blower which supplies forced ventilation to the main motors.

In the corridor is mounted a nickel-cadmium battery which supplies the auxiliary services in an emergency, should the low voltage generator fail.

The end compartments are the driving cabs, and contain the master controller with the necessary brake valves, instruments, auxiliary switches, etc., for the driver's use in controlling the train.

The motors are controlled by means of contactors which are mounted in the high-tension compartment. These contactors make various motor combinations and insert the appropriate resistances in the main circuit of the motors under the control of the master controller and overload relays.

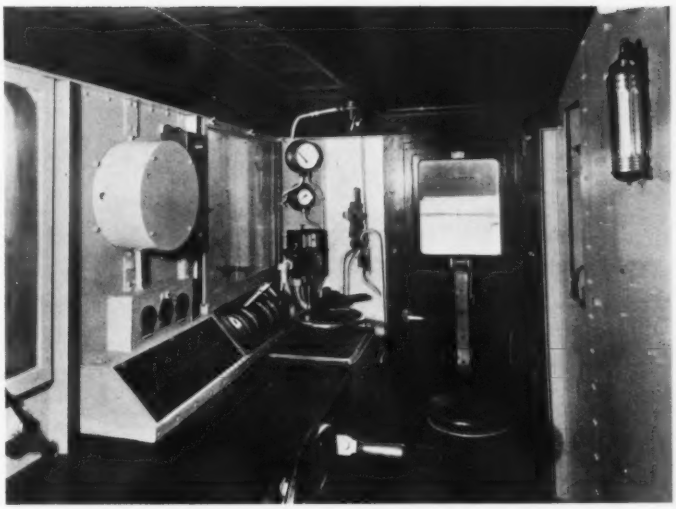


Fig. 13.—Locomotive Cab showing master controller and instruments.

The control is of the Metropolitan-Vickers electro-pneumatic unit switch type, in which the contactors are individual switches of the air-break type, with magnetic blowout. A very high pressure is maintained between the contacts, which are closed by means of compressed air pistons, actuated through electrically operated air valves, and opened by very strong springs which prevent any possibility of the contacts freezing when called upon to open very heavy currents.

The reverser is a two-position drum type switch operated by a compressed air engine, and reverses the current in the main fields.

The electrically operated air valves which actuate the pistons of the unit switches are controlled through the master controller in the driver's cab. This master controller is of the drum type with two drums, one for reversing and the other for effecting the required combinations of control circuits. The driving drum has thirty-two control notches, which provide for a sufficient number of resistance steps together with the series parallel combination and three stages of field weakening.

A Westinghouse automatic air brake system is installed for operating the brakes on the locomotive and the train, and an independent straight air brake is also provided on the locomotive.

Separate brake cylinders are fitted to each bogie, and operate a system of levers and balance beams, which cause equal pressure to be applied to the blocks. In addition a hand brake is fitted which operates through a hand wheel and screw conveniently placed in each driving position, and so arranged that power is applied separately from each driver's stand, and also independently to each bogie.

Because of the severe climatic conditions, double windows with air space between are fitted in front of the driver, and a powerful air-operated window wiper is provided; also heaters are fitted in the driver's cab.

The instruments consist of voltmeter and ammeter, together with speed indicator and recorder.

In connection with the signal system, lever arms are provided on the track which in the danger position will operate a train stopping device, thus cutting out the control and applying the brakes independently of the driver.

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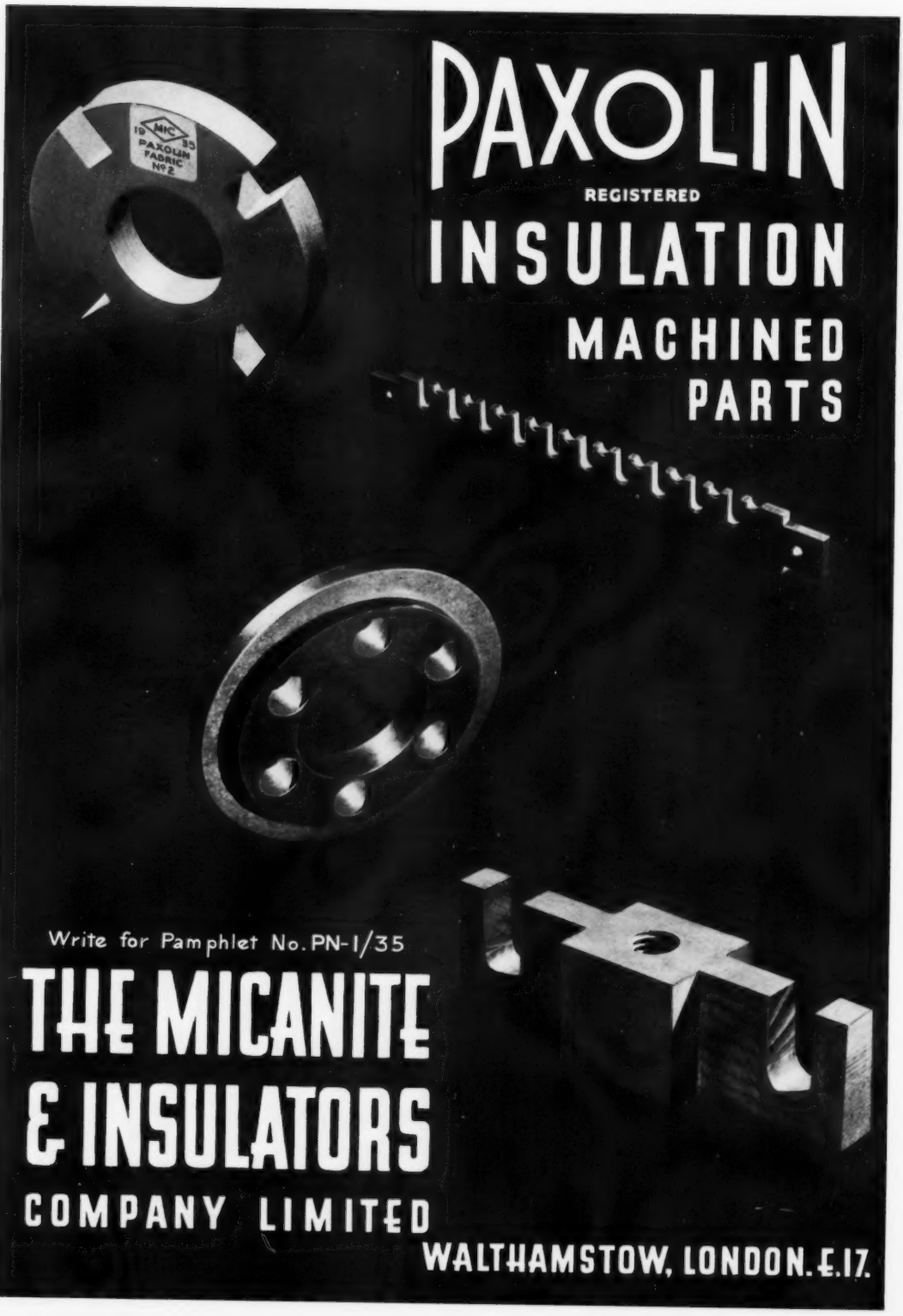
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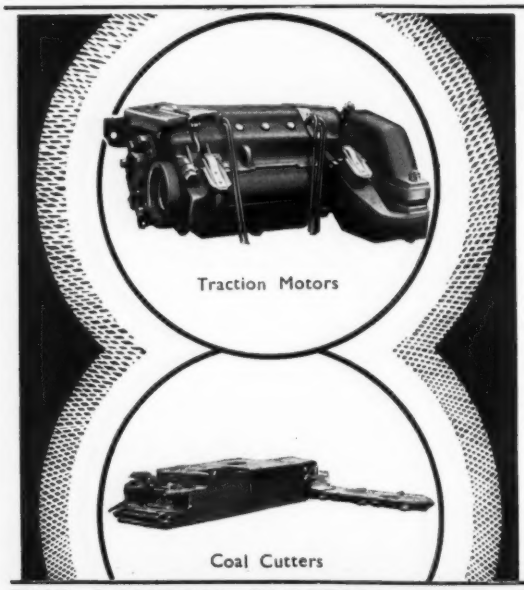

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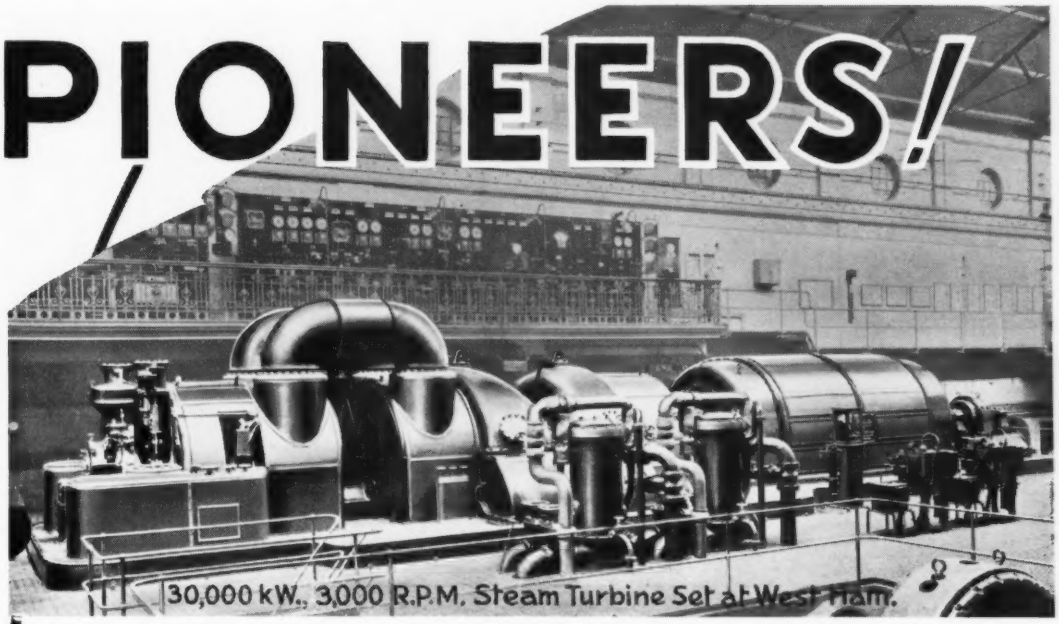

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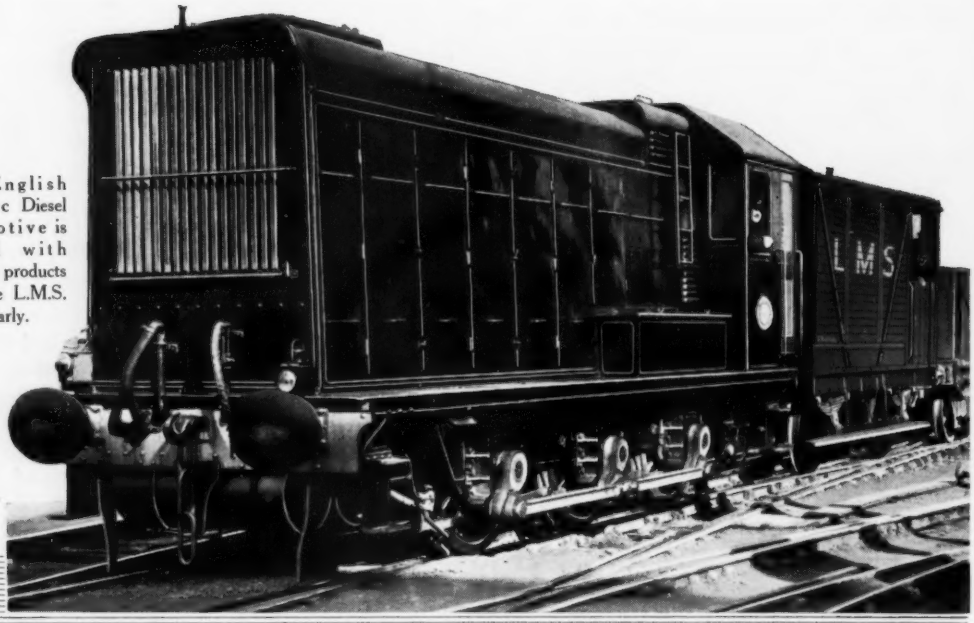

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